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Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Headwater Slope Wetlands on the South Carolina Coastal Plain

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Final report

Abstract: The Hydrogeomorphic (HGM) Approach is a system for developing functional indices to assess a wetland's capacity to perform functions similar to those of comparable wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence. This Regional Guidebook (a) characterizes the Headwater Slope wetlands on the South Carolina Coastal Plain; (b) describes and provides the rationale used to select functions for the Headwater Slope wetland subclass; (c) describes model variables and metrics; (d) describes the development of assessment models; (e) provides data from reference wetlands and documents their use in calibrating model variables and assessment models; and (f) outlines protocols for applying the functional indices to the assessment of wetland functions.

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Preface

This Guidebook extends the previously published Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Headwater Slope Wetlands on the Mississippi and Alabama Coastal Plains (Noble et al. 2007) to a new reference domain. That work was performed by the U.S. Army Engineer Research and Development Center (ERDC) under a Cooperative Research and Development Agreement with the Mississippi Department of Marine Resources (MDMR). Funding was provided by a grant from the U.S. Environmental Protection Agency, Region IV, to MDMR. The assessment models and application instructions in this guidebook are largely the same as those in the earlier work but the variable subindex curves have been recalibrated as needed using reference data collected from South Carolina's Coastal Plain.

The reference data were collected and summarized in a draft report by the South Carolina Department of Health and Environmental Control, under contract to the Environmental Protection Agency (EPA), Region IV. In order to produce a guidebook consistent with Noble et al. (2007), the manuscript from that earlier report was not used here, but the data were used to calibrate the model variables to the extent possible.

This report was adapted by Elizabeth Murray, Chris Noble, Dr. Charles V. Klimas, and Jeff Lin of the Wetlands and Coastal Ecology Branch (WCEB), Environmental Laboratory (EL), ERDC, and William Ainslie (EPA Region IV) from the original Headwater Slope Guidebook prepared by Chris Noble and Dr. James S. Wakeley (WCEB); Dr. Thomas H. Roberts, Tennessee Technological University, Cookeville; and Cindy Henderson, MDMR. Many of the descriptions of functions, models, and variables are little changed from that guidebook. Significant changes are primarily in the description of the reference domain, relevant soils and plant species, and subindex curves of the variables. The development of this report was funded by EPA Region IV and by the Wetland Regulatory Assistance Program (WRAP) administered by ERDC.

At the time the final draft of this report was prepared, Dr. Edmund Russo was Acting Chief of the WCEB; Dr. Russo was also Chief, Ecosystem

1   Introduction

Background

The Hydrogeomorphic (HGM) Approach is a system for developing functional indices to assess a wetland's capacity to perform functions similar to those of comparable wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review process to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including determining minimal effects under the Food Security Act, designing wetland restoration projects, and managing wetlands.

On 16 August 1996, a National Action Plan (NAP) to Implement the Hydrogeomorphic Approach was adopted (Federal Register 1997). The NAP was developed cooperatively by a National Interagency Implementation Team consisting of the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highways Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). The NAP outlines a strategy to promote the development of Regional Guidebooks for assessing the functions of regional wetland subclasses using the HGM Approach; provides guidelines and a set of tasks required to develop Regional Guidebooks; and solicits the cooperation and participation of Federal, State, and local agencies, academia, and the private sector in this effort.

This guidebook is based on a template developed for headwater wetlands in the Gulf Coastal Plain (Noble et al. 2007), and adopts most of the assessment models, variables, field indicators, and rationale employed in that earlier work. However, many of the model variables were calibrated using a data set previously collected by the South Carolina Department of Health and Environmental Control (SCDHEC) (2003) under a contract with Region IV of EPA.

Objectives

The objectives of this Regional Guidebook are to (a) characterize the Headwater Slope wetlands in the Coastal Plain of South Carolina; (b) describe and provide the rationale used to select functions for the Headwater Slope wetland subclass; (c) describe model variables and metrics; (d) describe the development of assessment models; (e) provide data from reference wetlands and document their use in calibrating model variables and assessment models; and (f) outline the necessary protocols for applying the functional indices to the assessment of wetland functions.

Scope

This guidebook is organized in the following manner. Chapter 1 provides the background, objectives, and organization of the guidebook. Chapter 2 summarizes the major components of the HGM Approach and the development and application phases required to implement the approach. Chapter 3 characterizes the Headwater Slope wetland subclass in the Coastal Plain of South Carolina in terms of geographical extent, climate, geomorphic setting, hydrology, vegetation, soils, and other factors that influence wetland function. Chapter 4 discusses each of the wetland functions, model variables, and functional indices. This discussion includes a definition of each function; a quantitative, independent measure of the function for the purposes of model validation; a description of the wetland ecosystem and landscape characteristics that influence the function; a definition and description of model variables used to represent these characteristics in the assessment model; a discussion of the assessment model used to derive the functional index; and an explanation of the rationale used to calibrate the index with reference wetland data. Chapter 5 outlines the steps in the protocol for conducting a functional assessment of Headwater Slope wetlands in the Coastal Plain of South Carolina. Appendix A presents a Glossary. Appendix B contains supplementary information on model variables.

2 Overview of the Hydrogeomorphic Approach

Development and application phases

The HGM Approach is conducted in two phases: Development and Application. An interdisciplinary Assessment Team of experts carries out the Development Phase, which results in the production of a Regional Guidebook that presents a set of models and protocols to be used in assessing the functional performance of one or more regional wetland subclasses. The Application Phase consists of the use of that Regional Guidebook in any of a variety of regulatory or planning tasks where wetland functions are of interest (Figure 1).
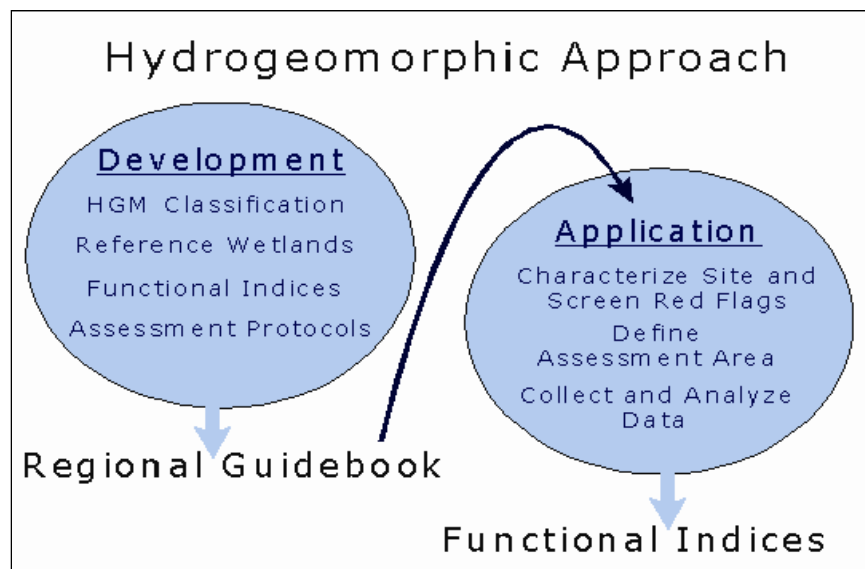
Figure 1. Development and Application Phases of the HGM Approach (from Ainslie et al. 1999).

In developing a Regional Guidebook, the Assessment Team completes the tasks outlined in the National Action Plan for Implementation of the HGM Approach (Federal Register 1997). After organization and training, the first task of the team is to classify the wetlands of the region of interest into regional wetland subclasses using the principles and criteria of Hydrogeomorphic Classification (Brinson 1993; Smith et al. 1995). Next, focusing on a specific regional wetland subclass, the team develops an ecological characterization or functional profile of the subclass. The

Assessment Team then identifies the important wetland functions, conceptualizes assessment models, identifies assessment variables to represent the characteristics and processes that influence each function, and defines metrics for quantifying assessment variables. Next, reference wetlands are identified to represent the range of variability exhibited by the regional subclass, and field data are collected and used to calibrate assessment variables and indices used in the assessment models. Finally, the team develops the assessment protocols necessary for regulators, managers, consultants, and other end users to apply the indices to the assessment of wetland functions.

During the Application Phase, the assessment variables, models and protocols are used to assess wetland functions. This involves two steps. The first is to apply the assessment protocols outlined in the Regional Guidebook to complete the following tasks:

- Define assessment objectives
- Characterize the project site
- Screen for red flags
- Define the Wetland Assessment Area
- Collect field data
- Analyze field data

The second step involves applying the results of the assessment at various decision-making points in the planning or permit review sequence, such as alternatives analyses, impact minimization, assessment of unavoidable impacts, determination of compensatory mitigation, design and monitoring of mitigation, comparison of wetland management alternatives or results, determination of restoration potential, or identification of acquisition or mitigation sites. Each of the components of the HGM Approach that are developed and integrated into the Regional Guidebook is discussed briefly below. More extensive treatment of these components can be found in Brinson (1993; 1995a,b), Brinson et al. (1995, 1996, 1998), Smith et al. (1995), and Hauer and Smith (1998).

The Development Phase of the HGM Approach utilizes concepts and methods to develop functional indices for assessing the capacity of a wetland to perform functions relative to similar wetlands in a region. The HGM Approach includes four integral components: (a) the HGM classification, (b) reference wetlands, (c) assessment models/functional

indices, and (d) assessment protocols. During the development phase of the HGM Approach, these four components are integrated into a Regional Guidebook for assessing the functions of a regional wetland subclass. During the application phase, end users — following the assessment protocols outlined in the Regional Guidebook — assess the functional capacity of selected wetlands. Each of the components of the HGM Approach and the development and application phases are discussed in this chapter. More extensive discussions can be found in Brinson (1993; 1995a, b); Brinson et al. (1995, 1996, 1998); Smith et al. (1995); Hauer and Smith (1998); Smith (2001); Smith and Wakeley (2001); and Wakeley and Smith (2001).

Hydrogeomorphic classification

Wetland ecosystems share a number of features including relatively long periods of inundation or saturation, hydrophytic vegetation, and hydric soils. In spite of these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and exhibit a wide variety of physical, chemical, and biological characteristics and processes (Cowardin et al. 1979; Semeniuk 1987; Ferren et al. 1996a, 1996b, 1996c; Mitsch and Gosselink 2000). The variability of wetlands makes it challenging to develop assessment methods that are both accurate (i.e., sensitive to significant changes in function) and practical (i.e., that can be completed in the relative short time frame available for conducting assessments). Existing "generic" methods designed to assess multiple wetland types throughout the United States are relatively rapid, but lack the resolution necessary to detect significant changes in function. However, one way to achieve an appropriate level of resolution within the available time frame is to reduce the level of variability exhibited by the wetlands being considered (Smith et al. 1995).

The HGM Classification was developed specifically to accomplish this task (Brinson 1993). It identifies groups of wetlands using three criteria that fundamentally influence how wetlands function: geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the landform and position of the wetland in the landscape. Water source refers to the primary water source in the wetland such as precipitation, overbank floodwater, or groundwater. Hydrodynamics refers to the level of energy and the direction that water moves in the wetland. Based on these three classification criteria, any number of "functional" wetland groups can be identified at different spatial or temporal scales. For example, at a continental scale, Brinson

(1993) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 1 (Smith et al. 1995). In many cases, the level of variability in wetlands encompassed by a continental scale hydrogeomorphic class is still too great to allow development of assessment models that can be rapidly applied while being sensitive enough to detect changes in function at a level of resolution appropriate to the Section 404 review process. For example, at a continental geographic scale, the depression class includes wetland ecosystems in different regions as diverse as California vernal pools (Zedler 1987), prairie potholes in North and South Dakota (Hubbard 1988; Kantrud et al. 1989), playa lakes in the high plains of Texas (Bolen et al. 1989), kettles in New England, and cypress domes in Florida (Ewel 1984; Kurz and Wagner 1953).

To reduce both inter- and intraregional variability, the three classification criteria are applied at a smaller, regional geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (Stewart and Kantrud 1971; Golet and Larson 1974; Wharton et al. 1982; Ferren et al. 1996a, 1996b, 1996c). Regional subclasses, like the continental classes, are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. In addition, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain regions. For example, depressional subclasses might be based on water source (i.e., groundwater versus surface water), or the degree of connection between the wetland and other surface waters (i.e., the flow of surface water in or out of the depression through defined channels). Tidal fringe subclasses might be based on salinity gradients (Shafer and Yozzo 1998). Slope subclasses might be based on the degree of slope, landscape position, the source of water (i.e., throughflow versus groundwater), or other factors. Riverine subclasses might be based on water source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 2, Smith et al. (1995), and Rheinhardt et al. (1997).

Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of its geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process.

Table 1. Hydrogeomorphic Wetland Classes at the Continental Scale.

HGM Wetland Class	Definition
Depression	Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater/interflow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression. The predominant hydrodynamics are vertical fluctuations that range from diurnal to seasonal. Depressional wetlands may lose water through evapotranspiration, intermittent or perennial outlets, or recharge to groundwater. Prairie potholes, playa lakes, vernal pools, and cypress domes are common examples of depressional wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal current diminishes and river flow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine classes is where bidirectional flows from tides dominate over unidirectional flow controlled by floodplain slope of riverine wetlands. Because tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. *Spartina alterniflora* salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. In some cases, these wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional, usually controlled by water-level fluctuations resulting from wind or seiche. Lacustrine wetlands lose water by flow returning to the lake after flooding and by evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.
Slope	Slope wetlands are found in association with the discharge of groundwater to the land surface or sites with saturated overflow with no channel formation, or a channel that only serves to convey water away from the slope wetland, rather than deliver water to it. They normally occur on sloping land ranging from slight to steep. The predominant source of water is groundwater or interflow discharging at the land surface. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, via a low-order stream, and by evapotranspiration. Slope wetlands are distinguished from depressional wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands.
Mineral Soil Flats	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. They typically occur in relatively humid climates. Pine flatwoods with hydric soils are examples of mineral soil flat wetlands.
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of the convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are examples of organic soil flat wetlands.

HGM Wetland Class	Definition
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In headwaters, riverine wetlands often intergrade with slope wetlands, depressions, poorly drained flats, or uplands as the channel (bed) and bank disappear. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evaporation. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long periods of saturation from groundwater sources. Bottomland hardwoods on floodplains are an example of riverine wetlands.

Table 2. Potential regional wetland subclasses in relation to geomorphic setting, dominant water source, and hydrodynamics.

Geomorphic Setting	Dominant Water Source	Dominant Hydrodynamics	Potential Regional Wetland Subclasses	
			Eastern USA	Western USA/Alaska
Depression	Groundwater or interflow	Vertical	Prairie potholes, marshes, Carolina bays	California vernal pools
Fringe (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake marshes
Slope	Groundwater	Unidirectional, horizontal	Headwater wetlands	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (organic soil)	Precipitation	Vertical	Peat bogs; portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizontal	Bottomland hardwood forests	Riparian wetlands

Reference wetlands

Reference wetlands are wetland sites selected to represent the range of variability that occurs in a regional wetland subclass as a result of natural processes and disturbance (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as cultural alteration. The reference domain is the geographic area occupied by the reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the reference domain will

mirror the geographic area encompassed by the regional wetland subclass; however, this is not always possible due to time and resource constraints.

Reference wetlands serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of function across the suite of functions selected for a regional wetland subclass. Second, they establish the range and variability of conditions exhibited by model variables. Reference wetlands also provide the data necessary for calibrating model variables and assessment models. Lastly, they provide a concrete physical representation of wetland ecosystems that can be observed and measured.

Reference standard wetlands are the subset of reference wetlands that perform the suite of functions selected for the regional subclass at a level that is characteristic in the least altered wetland sites in the least altered landscapes. Table 3 outlines the terms used by the HGM Approach in the context of reference wetlands.

Table 3. Reference wetland terms and definitions.

Term	Definition
Reference domain	The geographic area from which reference wetlands representing the regional wetland subclass are selected (Smith et al. 1995).
Reference wetlands	A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and disturbance and from human alterations.
Reference standard wetlands	The subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human-altered wetland sites in the least human-altered landscapes. By definition, functional capacity indices for all functions in reference standard wetlands are assigned a value of 1.0.
Reference standard wetland variable condition	The range of conditions exhibited by model variables in reference standard wetlands. By definition, reference standard conditions receive a variable subindex score of 1.0.
Site potential (mitigation project context)	The highest level of function possible, given local constraints of disturbance history, land use, or other factors. Site potential may be less than or equal to the levels of function in reference standard wetlands of the regional wetland subclass.
Project target (mitigation project context)	The level of function identified or negotiated for a restoration or creation project.
Project standards (mitigation context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

Assessment models and functional indices

In the HGM Approach, an assessment model is a simple representation of a function performed by a wetland ecosystem. It defines the relationship between one or more characteristics or processes of the wetland ecosystem. Functional capacity is simply the ability of a wetland to perform a function compared to the level of performance in reference standard wetlands.

Model variables represent the characteristics of the wetland ecosystem and surrounding landscape that influence the capacity of a wetland ecosystem to perform a function. Model variables are ecological quantities that consist of five components (Schneider 1994): (a) a name, (b) a symbol, (c) a measure of the variable and procedural statements for quantifying or qualifying the measure directly or calculating it from other measures, (d) a set of variables (i.e., numbers, categories, or numerical estimates (Leibowitz and Hyman 1997)) that are generated by applying the procedural statement, and (e) units on the appropriate measurement scale. Table 4 provides several examples.

Table 4. Components of a model variable.

Name (Symbol)	Measure / Procedural Statement	Resulting Values	Units (Scale)
Number of canopy trees (V_{CTDEN})	Average number of canopy trees	0 to $\geq$20	unitless
Canopy tree diameter (V_{CTD})	Average diameter at breast height (dbh) of canopy trees	0.0 to >100.0	centimeters
Soil Detritus ($V_{DETRITUS}$)	Percent cover of soil detritus	0 to >100	percent

Model variables occur in a variety of states or conditions in reference wetlands. The state or condition of the variable is denoted by the value of the measure of the variable. For example, percent soil detritus, the measure of the percent cover of soil detritus, could be large or small. Based on its condition (i.e., value of the metric), model variables are assigned a variable subindex. When the condition of a variable is within the range of conditions exhibited by reference standard wetlands, a variable subindex of 1.0 is assigned. As the condition deflects from the reference standard condition (i.e., the range of conditions within which the variable occurs in reference standard wetlands), the variable subindex is assigned based on the defined relationship between model variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard wetlands, it receives a progressively lower subindex reflecting its decreasing contribution to functional capacity. In

some cases, the variable subindex drops to zero. For example, when the percent cover of soil detritus is 95 percent or greater, the subindex for percent herbaceous groundcover is one. As the percent cover falls below 95 percent, the variable subindex score decreases on a linear scale to zero.

Model variables are combined in an assessment model to produce a functional capacity index (FCI) that ranges from 0.0 to 1.0. The FCI is a measure of the functional capacity of a wetland relative to reference standard wetlands in the reference domain. Wetlands with an FCI of 1.0 perform the function at a level characteristic of reference standard wetlands. As the FCI decreases, it indicates that the capacity of the wetland to perform the function is less than that characteristic of reference standard wetlands.

Assessment protocol

The final component of the HGM Approach is the assessment protocol. The assessment protocol is a series of tasks, along with specific instructions, that allow the end user to assess the functions of a particular wetland area using the functional indices in the Regional Guidebook. The first task is characterization, which involves describing the wetland ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the wetland areas to be assessed. The second task is collecting the field data for model variables. The final task is analysis, which involves calculation of functional indices. These steps are described in detail in Chapter 5, and the required data forms, spreadsheets, and supporting digital spatial data are provided in the appendices.

3 Characterization of Headwater Slope Wetlands on the Coastal Plain of South Carolina

Regional Wetland Subclass and Reference Domain

This Regional Guidebook was developed to assess the functions of Headwater Slope wetlands on the Coastal Plain of South Carolina. Within the reference domain, Headwater Slope wetlands occur primarily as linear drainages within a flat or rolling upland landscape. For the purpose of this guidebook, the subclass is defined as the wetlands in headwater areas above and including first- and second-order (Strahler 1952) streams, in which groundwater is the primary hydrologic input (Figure 2); the channels carry water away from the wetlands, rather than deliver water to them, and thus the wetlands are not a Riverine subclass, despite the presence of the channel. The combination of landscape position and dominance of ground-water hydrology place these wetlands in the slope HGM class. Other names used to refer to wetlands in the regional subclass include bayheads, bay galls, springheads, and steepheads.

Development of this Guidebook was initiated, in part, to meet the needs of federal and state agencies for a procedure to assess existing and potential wetland impacts and potential mitigation sites in the Coastal Plain of South Carolina. For the purposes of this report, the Coastal Plain of South Carolina comprises two Major Land Resource Areas (U.S. Department of Agriculture (USDA) Natural Resources Conservation Service 2006) within South Carolina: the Southern Coastal Plain and the Atlantic Coast Flatwoods (Figure 3). Reference wetland sampling in South Carolina occurred in the headwaters of the Salkahatchie, Edisto, Santee, and Pee Dee River basins, located in six counties: Berkeley, Dorchester, Colleton, Charleston, Florence, and Horry; they and were selected based on site conditions, accessibility of the sites, permission of landowners, time and resources.

The *potential* reference domain (i.e., the maximum geographic extent of the wetland subclass) (Smith et al. 1995) includes much of the Coastal Plain from Maryland to Texas, where Headwater Slope wetlands occur. However, the models in this guidebook were calibrated using data from reference wetlands in the Coastal Plain of South Carolina and data

Figure 2. Example of a Headwater Slope wetland surrounding a first-order stream. The Headwater Slope wetland subclass does not include floodplain wetlands along higher-order streams, which receive hydrologic inputs from the stream itself.
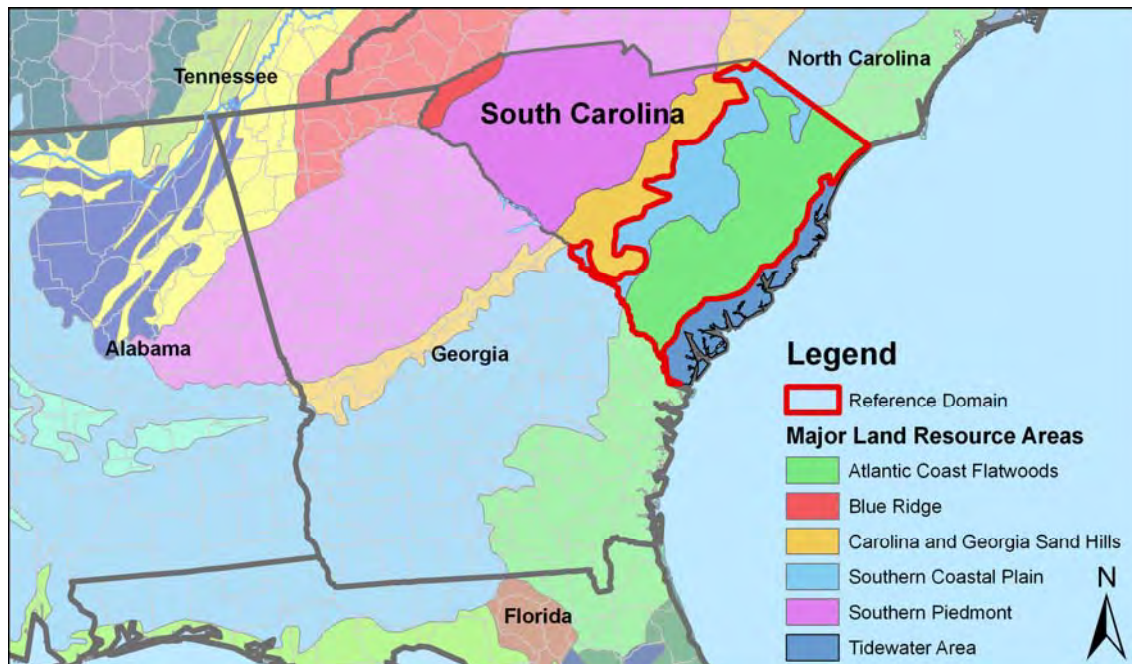
Figure 3. The southeast United States highlighting South Carolina, divided into Major Land Resource Areas (USDA Natural Resources Conservation Service 2006). The reference domain for this Guidebook includes the Southern Coastal Plain and the Atlantic Coast Flatwoods within South Carolina, henceforth referred to as the Coastal Plain of South Carolina.

collected for Headwater Slope wetlands in Mississippi and Alabama. These models may be applicable to Headwater Slope wetlands located elsewhere in the potential reference domain. Persons wishing to apply the models in other areas, however, should collect additional reference data to revise the plant lists and recalibrate the subindex graphs.

Characterization of the Regional Subclass

Physiography and geology

The Coastal Plain is one of eight physiographic divisions described by Fenneman (1938) and consists of the broad, low-lying area along the immediate coastline extending from New England southward along the Atlantic Ocean and westward along the Gulf of Mexico to Texas and Mexico. The Coastal Plain is the inner portion of the Continental Shelf that has been covered by shallow seas periodically since the Mesozoic era, as evidenced by the various types of sedimentary deposits of Cretaceous age and younger that underlie it. During the most recent Ice Ages, the entire Continental Shelf was exposed due to vast volumes of the earth's water being tied up in glaciers and the polar ice caps. As the Ice Ages ended, meltwater inundated the outer portion of the Continental Shelf while the slightly higher, inner portion (i.e., the Coastal Plain) has remained exposed for approximately the past 10,000 years.

The Coastal Plain has been subjected to repeated differential movements that have resulted in a series of highs and intervening sags in the basement rock surface and overlying sediments along the entire coastline (Cederstrom et al. 1979). Cederstrom et al. (1979) described the underlying sediments of the Coastal Plain as unconsolidated clay, sand, and gravel, and unconsolidated or semi-consolidated limestone. The deposits, which range in age from Cretaceous to Holocene, form an arch that extends from Virginia through the Carolinas, Georgia, and Alabama into eastern Mississippi. The deposits are thin near the Fall Line and thicken toward the coast.

Generally, the Coastal Plain beds have a gentle slope or "dip" seaward. Each formation has been overlapped by the next younger formation and their eroded edges are now exposed in a succession of older (inland) to younger (seaward) arcuate belts. Formations are rarely uniform laterally or down-dip. Nearshore, sandy, deltaic continental sediments thicken downdip and grade into deeper water silty or limy marine deposits. Laterally, sediments also may change in proportion of sand and clay, or may become limy. Sandy

terrace deposits were superimposed upon the older formations during the Pleistocene Epoch (Cederstrom et al. 1979). The current form of the Coastal Plain from Chesapeake Bay to eastern Texas is largely the result of sediment deposition, both alluvial and marine, from the adjacent eroding mountains and Piedmont. It has been sculpted by hydrologic and fluvial geomorphologic processes that vary in their effect in response to changes in sea level and climate (Hupp 2000). In the Southeast, the Coastal Plain averages 100-200 miles (160-320 km) wide and is bordered to the interior by a highland area known as the Piedmont. The portion of the Coastal Plain of South Carolina covered in this guidebook excludes the tidelands and sandhills, and averages about 80 miles wide. It has been sculpted by hydrologic and fluvial geomorphologic processes that vary in their effect in response to changes in sea level and climate (Hupp 2000).

The Coastal Plain in South Carolina occupies approximately the southeastern two-thirds of the state (SC Water Resources Commission 1983). Underlain by a veneer of Cretaceous and Cenozoic sediments, the Coastal Plain has been submerged beneath the Atlantic Ocean at various times in the geologic past (Horton and Zullo 1991). It exhibits moderate to low relief including several terraces, which represent former sea levels (SC Water Resources Commission 1983). The Atlantic Coast Flatwoods area has elevations that range from sea level to about 125 ft and a topography typified by gently sloping landscapes dissected by broad valleys with meandering streams (SC Water Resources Commission 1983).

The Coastal Plain provinces of South Carolina comprise unconsolidated sediments, including sand, gravel, clay, limestone, marl, coquina, shale, and shell-packed clay. In these regions, many of the sedimentary aquifers are able to store and transmit large volumes of groundwater. The Black Creek and the Tertiary Limestone aquifers are located in counties of both the Atlantic Coast Flatwoods and the Southern Coastal Plain areas (SCWRC 1993). The sedimentary formations of the Southern Coastal Plain are older, more dissected, and generally more xeric than the flatter terraces of the Atlantic Coast Flatwoods area, but still support significant concentrations of Headwater Slope wetlands. In contrast, the nearly-level Atlantic Coast Flatwoods have wider upland surfaces and larger areas of poorly drained soils (Griffith et al. 2002).

Climate

The climate of South Carolina is most influenced by its latitude and its proximity to the Atlantic Ocean to the east and the Appalachian mountains in the west. South Carolina is situated in a humid, subtropical region with cool winters and long hot summers (Sidlow et. al. 1995). The state's average annual temperature ranges from 55°F (13°C) in the mountains to about 63°F (17°C) along the coast and winds are predominantly southwesterly and northeasterly over most land areas (SC State Water Assessment 1983; South Carolina Department of Natural Resources State Climatology Office 2009). Seasonal rainfall in the state is usually greatest in the early spring and summer and least in mid to late spring and autumn (Sidlow et. al. 1995). However, Miwa et al (2002) indicated that rainfall can be evenly distributed throughout the year. Evapotranspiration is greater in the late spring through early autumn months creating a soil water deficit. The annual rainfall in the Atlantic Coastal Plain Region averages 48 to 50 in., similar to the lower Piedmont. Mean precipitation during the growing season ranges from 31 to 37 in., and the length of the average growing season is 220 to 280 days (Ellerbe 1974).

In South Carolina, severe weather often includes thunderstorms and tornadoes in late winter and spring. In summer and fall, hurricanes periodically strike coastal areas, also causing extensive damage well inland. For example, in 1989, Hurricane Hugo caused severe damage to forest resources in 26 counties in the state, including most of the counties within the reference domain of this guidebook (Sheffield and Thompson 1992). Less intense but more frequent tropical storms and depressions contribute significantly to annual rainfall in the summer and fall months (Sidlow et al. 1995). Winter precipitation is generally rain, but light snow, sleet and freezing rain can occur between December and early March (South Carolina Department of Natural Resources State Climatology Office 2009).

Geomorphic setting

The Headwater Slope subclass is defined in this guidebook as occurring in headwater areas above and including first- and second-order streams where groundwater discharge is the major hydrologic input. Similar plant communities may occur in other geomorphic settings not covered in this guidebook, such as depressions in flatwoods and the edges of large floodplains. Headwater Slope wetlands often grade into other wetland subclasses, such as wet flats, tidal fringes, or riverine systems associated

with second or higher order streams. They occur in relatively flat areas, in areas that are gently sloping, and in drainages with pronounced side slopes. Shallow channels may be present in some Headwater Slope wetlands, but where they occur they are often poorly defined or braided. Figure 4 illustrates the landscape setting in which Headwater Slope wetlands occur. While Headwater Slope wetlands are sometimes difficult to classify because they intergrade with other HGM classes, including flats and riverine systems, reliance on hydrologic indicators will lead to correct classification. A narrow floodplain may be present in the headwater zone, but the principal source of wetland hydrology is groundwater from the adjacent slopes. It becomes a riverine system when overbank flooding dominates.
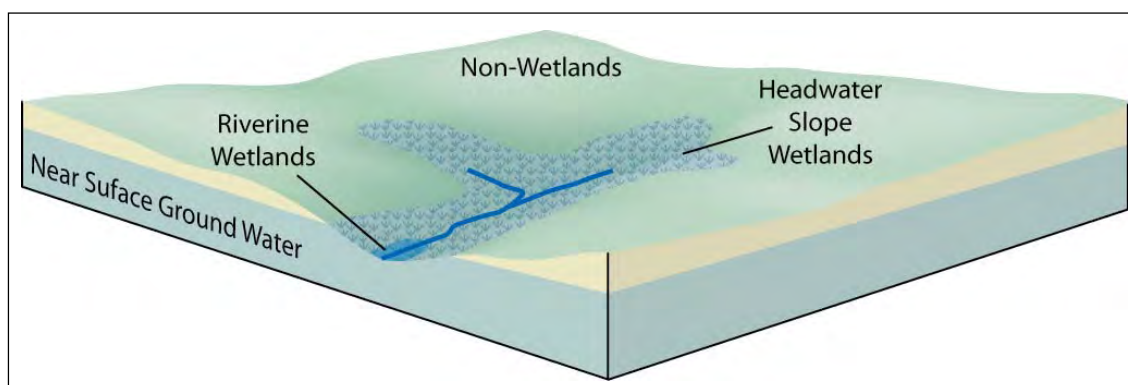
Figure 4. Generalized landscape position of Headwater Slope wetlands in the Coastal Plain of South Carolina.

Streams associated with reference wetlands exhibited slopes ranging from 0 to 10%, with an average slope of 1%. The slope from the wetland to upland ranged from 0 to 20%, with an average slope of 5.5%.

Hydrologic regime

One defining characteristic of Headwater Slope wetlands is that their primary source of hydrology is groundwater discharge (Nelson 1986, Vince et al. 1989). Even in wetlands where channels occur, flooding is not the major source of hydrology. In most Headwater Slope wetlands, near-surface saturation occurs for a portion of the growing season.

In low-gradient watersheds, like those in the Coastal Plain of South Carolina, water tables near low-order streams are close to the soil surface, with a capillary fringe above the water table (Williams 1998). Soils associated with this regional subclass often have clayey subsurface layers,

which restrict internal drainage. Rain added to the shallow water table results in rapid and large increases in water table height, which in turn causes a rapid increase in groundwater gradient to the stream, wetland soil saturation, and channel flow. Headwater Slope wetlands also deliver surface water from the surrounding watershed to the channel (Miwa et al. 2002). Headwater streams typically have low-gradient, relatively broad beds, which drain slowly.

Headwater Slope wetlands are rarely inundated for extended periods; surface water normally is present only after heavy rains. Ponding occurs in some wetlands, but only in microdepressions. Wetland soils may become depleted of moisture during dry periods due to evapotranspiration (Harms 1998).

Soils

In the Coastal Plain of South Carolina, soils were formed in unconsolidated marine silt and clay, marine sand, or beach marine sand deposits, and floodplain soils of the major rivers were formed from alluvial gravelly sand and alluvial silt/clay deposits (USDA 1981). These soils occupy broad flats and depressions and can generally be described as moderately well drained to poorly drained with subsoils that are generally loamy sand, sandy loam, clay, and some soft limestone. Loamy and clayey soils of the wet lowlands are predominant (Ellerbee 1974, SCWRC 1993). Wet sandy soils of broad ridges can be found in strips near the coast and extensively in Hampton County and are underlain by clayey and loamy soils. Well-mixed soils underlain by clayey and loamy soil layers are found in the floodplains of numerous rivers (SC Water Resources Commission 1983).

Major soil groups found in wetland areas covered by this Guidebook all formed from marine sediments and occur on nearly level floodplains. Typical soil series include Meggett, Grifton, Mouzon, Santee, Bladen, Argent, Bayboro, Bethera, and Rains. These soil series are classified as either alfisols [soils with an aquic (saturated long enough to produce reducing conditions) moisture regime and an argillic (clayey) horizon] or ultisols (soils that are saturated for some period of time and have an argillic horizon). The soils of these Headwater Slope wetlands provide limited water storage and are easily saturated, with excess water contributing to the flows of associated headwater streams.

Vegetation

Throughout the Coastal Plain of the United States, Headwater Slope wetlands may be dominated by a number of forest types, and called by different local names. For example, white cedar (*Chamaecyparis thyoides*) swamps (Wharton et al. 1977, Laderman 1989), hydric hammocks (Vince et al. 1989), titi (*Cyrilla racemiflora*) swamps (U.S. Army Corps of Engineers 1988), and Carolina bays (Laderman 1989) comprise many of the same species and are found in generally similar landscape positions. Wharton et al. (1977) indicated that the bayhead community may occur in a landscape mosaic of white cedar swamps, pond pine (*Pinus serotina*) woodland, and pocosins. They further noted that a number of communities may grade into bay forests.

Some variation in vegetation across the Coastal Plain is due to varying distribution of species, but additional variation depends on several environmental and disturbance gradients: the amount and seasonality of available water, fire frequency and intensity, and hydrologic modifications such as culverts and ditching. Wharton et al. (1977) stated that "bay forests are thought to succeed from Atlantic white cedar swamps in the absence of fire." USACE (1988) noted similar relationships between white cedar and bay swamps in Florida. Interestingly, fire intensity may be one of the factors that influence the interactions between these two types of headwater wetlands. Wharton et al. (1977) stated that severe fires may result in bay forests reverting to Atlantic white cedar. The role that fire plays in the dynamics of these communities is complex. Laderman (1989) noted that stands of white cedar may be destroyed by intense fire, but "light" fire reduces competition and permits cedar reproduction. Monk (1966, 1968) believed that bayheads are climax communities and may be "preceded (in succession) by pond pine or cypress wetlands." Fires occur in bayheads periodically and bays have apparently evolved adaptations to it. For example, Clewell (1971) noted that bays have the ability to sprout from top-killed stumps.

Within the Coastal Plain of South Carolina, several forest communities may dominate a reference standard Headwater Slope wetland, depending on local hydrologic conditions. At the headward extent, when there are infrequent, low-intensity fires, regular soil moisture, and few channels removing water, the vegetation becomes dominated by "bays" including sweetbay (*Magnolia virginiana*), southern magnolia (*M. grandiflora*), red bay (i.e., swamp bay) (*Persea borbonia*) in the overstory or midstory

(Monk 1966, Nelson 1986, Wharton et al. 1977, USACE 1988). In contrast, the wettest portions of the subclass – where several headwater slopes converge but any channels present are still inefficient at carrying away flow – support baldcypress (*Taxodium distichum)*, water tupelo *(Nyssa aquatica)*, and swamp tupelo (*Nyssa sylvatica* var. *biflora*). Bald cypress is sometimes absent from these sites due to past logging. In topographic high points along the wetland/upland margin, soil saturation occurs irregularly for brief periods, and extended dry periods are normal in summer. In these areas, a diverse forest typically occurs that is similar to floodplain systems of the region, with common dominants being various oaks (*Quercus spp*), hickories (*Carya spp*), spruce pine (*Pinus glabra*), loblolly pine (*Pinus taeda*), and sweetgum (*Liquidambar styraciflua*).

These forest types, while different, can occur in close proximity as a mosaic, and all receive local subsurface water flows as their main hydrologic input, so they are treated as a single HGM subclass in this guidebook.

Relationships to other wetland types

The Headwater Slope subclass grades into the Riverine class downstream, where stream flows become perennial, overbank flooding dominates the hydrologic regime of the wetlands, floodplains broaden, and a discernible natural levee may be present (Figure 4). This generally corresponds to the portion of the stream continuum where second-order streams transition to third-order streams.

Anthropogenic alterations

Before European settlement, South Carolina had approximately 4.7-6.4 million acres of wetlands comprising 24–32% of the landscape, of which 3.6 million acres were forested wetlands (Dahl and Johnson 1991; Dahl 1999). Prior to the 1700's, forested swamps were cleared to produce indigo and rice. After the Revolutionary War, indigo production dwindled, but rice culture continued to flourish and thousands of acres of virgin hardwoods and cypress were cleared for its production (Ellerbe 1974). Large portions of the original hardwood forests, including Headwater Slope wetlands, have been converted to loblolly pine plantations.

Rates of forested wetland loss in the South were greatest from the 1950's to the 1970's, but losses still occur due to agriculture and forestry practices

(Ainslie 2002). In addition, impoundment of streams for the purpose of creating recreational and storm water detention ponds and filling and leveling associated with commercial and residential development and road construction have further impacted many Headwater Slope wetlands. Until 1996, Headwater Slope wetlands were particularly vulnerable due to their typically small size - impacts to headwaters and wetlands of 10 acres or less were permitted under Nationwide Permit Number 26 issued by the U.S. Army Corps of Engineers. That regulatory exemption no longer applies. However, impacts related to changes in the size of the catchment and other influences on the sources and movement of the groundwater that sustains Headwater Slope wetlands are not regulated and continue to affect their distribution, character, and functions.

4 Wetland Variables, Functions, and Assessment Models

Variables

The following variables are used to assess the functions that are performed by Headwater Slope wetlands in South Carolina, in the order they appear on datasheets and spreadsheet calculators:

- Change in Catchment Size
- Upland Land Use
- Habitat Connections
- Soil Integrity
- Hydrologic Alterations
- Canopy Tree Diameter
- Canopy Tree Density
- Sapling/Shrub Cover
- Ground Vegetation Cover
- Vegetation Composition and Diversity
- Soil Detritus
- Surface Soil Organic Matter Content
- Woody Debris

Each variable is defined and the rationale for its selection is discussed in the following paragraphs. The relationship of each variable to functional capacity is also given, based on measurements taken in reference wetlands in the South Carolina, Alabama, and Mississippi Coastal Plains. Procedures for measuring each variable in the field can be found in Chapter 5.

Change in Catchment Size (V_{CATCH}). This variable is defined as the change in the size of the wetland catchment, watershed, or basin as a result of human activities in the wetland's landscape. The intent of this variable is to assess the change in the amount of water delivered to the wetland due to alterations to the watershed that either reduce or augment surface or subsurface flows. V_{CATCH} only applies to the hydrology function.

In the case of water diversions away from the Headwater Slope wetland due to ditches, berms, or other features in the catchment, the change is

quantified as a percent loss of catchment area by using the following formula (Equation 1):

$$Percent\ change = \left| \left(\frac{Natural\ catchment\ size - Existing\ catchment\ size}{Natural\ catchment\ size} \right) \times 100 \right| \quad (1)$$

In the case of water transfers into the wetland's catchment from another basin, the change is calculated as a percent increase in effective catchment area as follows (Equation 2):

$$Percent\ change = \left| \left(\frac{Area\ of\ catchment\ from\ which\ water\ is\ being\ transferred}{Wetland's\ natural\ catchment\ size} \right) \times 100 \right| \quad (2)$$

If the effective size of the catchment is unchanged (i.e., no water diversions), then the subindex score is 1.0. In Headwater Slope wetland reference sites, percent change in the size of the wetland catchment ranged from 0 to 73 percent. Reference standard wetland sites had no change in the size of the catchment (i.e., percent change = 0). The relationship between functional capacity and the percent change in catchment area is assumed to decline linearly to 0.1 when the percent change equals 100 (Figure 5). This is based on the assumption that, as the effective size of the catchment decreases, the amount of water entering the wetland is proportionately reduced and is not available to the wetland. However, the subindex does not go to zero because the wetland still receives direct precipitation and may receive subsurface input from the surrounding area. Additions of water to the wetland's catchment are also assumed to impact the natural hydrology of the wetland proportionally to its departure from the unaltered state. In the case of water transfers into the wetland's catchment, the percent change in effective catchment area can exceed 100 percent.
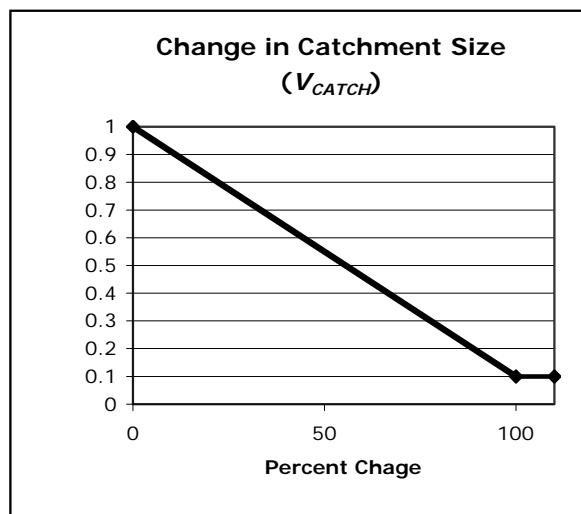
Figure 5. Change in effective size of the wetland catchment (V_{CATCH}) and functional capacity.

Upland Land Use (V_{UPUSE}). This variable is defined as the surface water runoff potential from the wetland catchment into the wetland. With increased disturbance and increased impervious surface surrounding the wetland, more surface water enters the wetland than it does under reference standard conditions. Burned natural areas should not receive an increased score. Runoff scores are based on runoff curves developed by the Natural Resources Conservation Service (USDA 1986). Runoff curve numbers are a function of land use and soil type. For this Headwater Slope guidebook, curve numbers are estimated based on land use and hydrologic soil groups A through D (Table 5). Hydrologic soil groups are based on soil properties such as texture and depth to restrictive layers. Aerial photographs depicting land use are available from a number of internet sources including TerraServer (http://terraserver.homeadvisor.msn.com/), Google Maps (http://maps.google.com/), and Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/). The last site also provides the most current soil survey maps. Hydrologic soil groups for soil series found within the reference domain can be found in Table B1 (Appendix B), local soil surveys, or at the Soil Data Mart (http://soildatamart.nrcs.usda.gov/). The subindex score for V_{UPUSE} is based on the weighted average of runoff scores for land uses and soils identified in the upland catchment of the Headwater Slope wetland (see Appendix B for an example calculation). V_{UPUSE} only applies to the hydrology function.

Headwater Slope reference standard wetlands were surrounded in their catchments by native vegetative communities. Under reference standard conditions, native upland plant communities have runoff scores of 55 or less and would receive a subindex of 1.0 (Figure 6). Instances of land use that significantly increase the amount of runoff into a Headwater Slope wetland are assumed to be detrimental to the characteristic hydrologic regime of the wetland. The subindex for this variable is assumed to decline linearly to zero as the weighted average runoff score increases from 55 to 98.
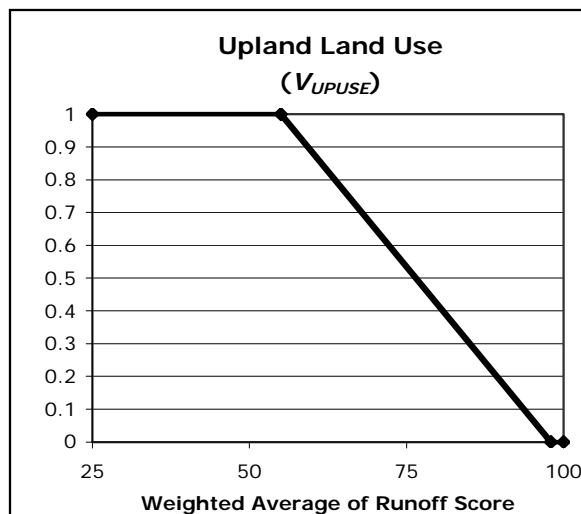
Figure 6. Relationship between the weighted average runoff score of the upland land use (V_{UPUSE}) and functional capacity.

Table 5. Runoff curve numbers.

Upland Land Use	Hydrologic soil groups			
Open space (pasture, lawns, parks, golf courses, cemeteries):	A	B	C	D
Poor condition (grass cover <50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)	49	69	79	84
Good condition (grass cover >75%)	39	61	74	80
Impervious areas (parking lots, roofs, driveways, etc)	98	98	98	98
Gravel	76	85	89	91
Urban districts:				
Commercial and business (85% cover)	89	92	94	95
Industrial (72% cover)	81	88	91	93
Residential districts by average lot size:				
1/8 acre or less (town houses and apartments) (65% cover)	77	85	90	92
1/4 acre (38% cover)	61	75	83	87
1/3 acre (30% cover)	57	72	81	86
1/2 acre (25% cover)	54	70	80	85
1 acre (20% cover)	51	68	79	84
2 acres (12% cover)	46	65	77	82
Newly graded areas (no vegetation or pavement)	77	85	90	92
Fallow crop areas (poor)	76	85	90	93
Fallow crop areas (good)	74	83	88	90
Row crops	70	80	86	90
Small grain	64	75	83	87
Groves and orchards (<50% ground cover)	57	73	82	86
Groves and orchards (50% to 75% ground cover)	43	65	76	82
Groves and orchards (>75% cover)	32	58	72	79
Forest and native range (<50% ground cover)	45	66	77	83
Forest and native range (50% to 75% ground cover)	36	60	73	79
Forest and native range (>75% ground cover)	30	55	70	77
Modified from USDA Natural Resources Conservation Service (1986)				

Habitat Connections ($V_{CONNECT}$). This variable is defined as the percentage of the wetland perimeter connected to suitable wetland or upland wildlife habitat, and the average width of the buffer wetland. To be considered in this calculation, a zone or buffer of suitable habitat must extend at least 10 m (32.8 ft) beyond the wetland boundary (Figure 7).

Suitable habitat is defined as natural plant communities that provide minimally suitable food, cover, and breeding sites for native wetland wildlife species, particularly reptiles and amphibians that depend on both wetlands and adjacent upland areas. Native forested areas of any age class, prairie, savanna, and scrub/shrub habitats are all suitable. Managed forests and pine plantations are considered suitable only if soils, litter, and ground-layer vegetation have not been disturbed extensively (e.g., bedded) such that cover has been eliminated and animal movement is impeded. Areas devoted to row crops, closely mowed areas, grazed pastures, and urban areas are not suitable habitat. $V_{CONNECT}$ applies only to the wildlife habitat function.
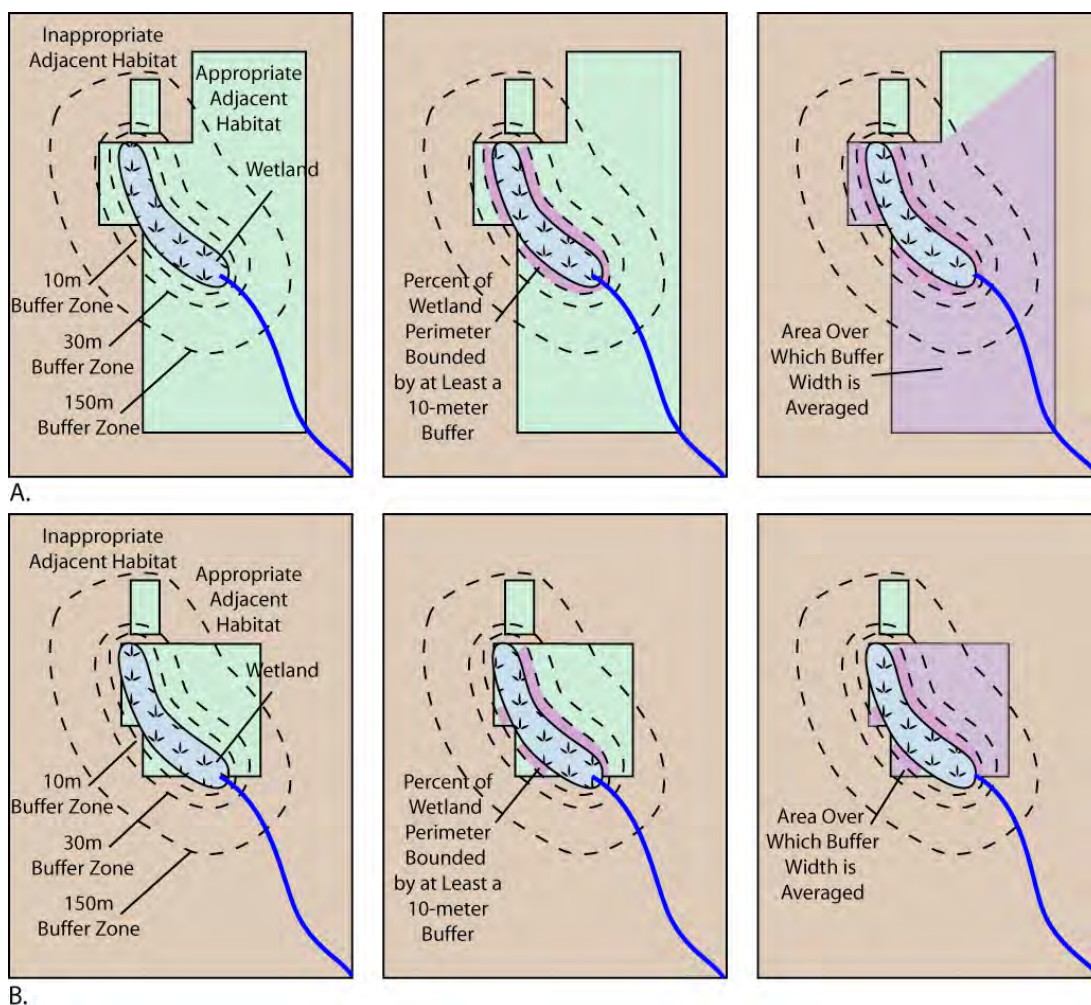
Figure 7. Illustration of values needed to calculate $V_{CONNECT}$. A. In this example, 80% of the wetland perimeter bounded by at least a 10-m-wide buffer (second panel), and the average buffer width is more than 150 m (third panel). B. In this example, only 50% of the wetland is bounded by appropriate habitat, and the average width is 80 m.

The width of the habitat that is connected to the wetland also is considered in this variable. Ideally a zone or buffer of suitable habitat should extend 150 m (492 ft) or more beyond the wetland boundary; that condition existed at all reference standard wetlands sampled. A narrower zone or buffer can, however, provide habitat for many amphibian, reptile, and avian species that utilize Headwater Slope wetlands; thus, the Connection Index in Figure 8 has three potential maximums. The top-most solid-line represents the primary calibration curve, when the average buffer width is $\geq$ 150 m (492 ft). A subindex value of 0.0 is assigned to sites where none of the wetland perimeter is buffered by at least a 10-m zone of suitable habitat. Reference standard wetlands have 85 to 100 percent of their perimeters suitably buffered by a zone at least 150 m (492 ft) wide. At sites where the percentage of the wetland perimeter with a suitable buffer at least 10 m (32.8 ft) wide is between zero and 85 percent, the relationship between the amount of suitable buffer and functional capacity is reduced (Figure 8, solid line series). If the average buffer width is $\geq$ 30 m and < 150 m (98.4-492 ft), the primary calibration curve is multiplied by 0.66 (middle dashed-line series, Figure 8). If the average buffer width is $\geq$ 10 m and < 30 m (32.8-98.4 ft), the calibration curve is multiplied by 0.33 (lowest dotted series, Figure 8). The resulting number is the subindex for $V_{CONNECT}$. For the examples shown in Figure 7, Example A has 80% of the perimeter buffered by an average width >150 m; thus, a variable subindex of 0.94; Example B has 50% of the perimeter buffered by an average width of 80 m, for a variable subindex of 0.39 (Figures 7 and 8).
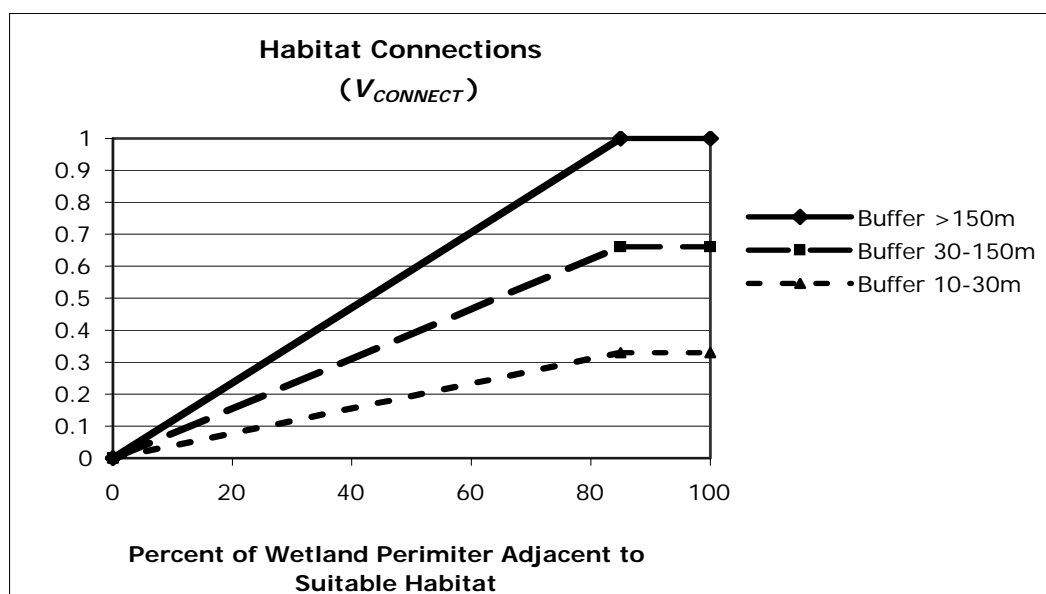
Figure 8. Relationship between the percentage of the wetland perimeter that is connected to suitable wildlife habitat, the width of the buffer, and functional capacity ($V_{CONNECT}$).

Soil Integrity ($V_{SOILINT}$). This variable is a measure of whether soil integrity has been altered at the site due to anthropogenic activity. Alterations to the soil can change both soil permeability and soil porosity, thereby affecting the subsurface movement and storage of water in the soil. Soil permeability will affect the rate at which subsurface water moves down the hydraulic gradient through Headwater Slope wetland soil and into the stream channel. When the velocity of subsurface water is high, subsurface water moves through the Headwater Slope wetland quickly, and the period of time that subsurface water discharges to the adjacent stream is short. Likewise, highly compacted soil can reduce soil permeability to the point that water does not infiltrate the soil, and moves quickly across the top of the soil, entering the adjacent stream rapidly. In unaltered soils, the velocity of subsurface water is slow, and discharge time to the adjacent stream occurs over a longer period. Soil porosity will affect the volume of space available below the ground surface for storing water after adjusting for antecedent moisture conditions (Dunne and Leopold 1978).

The integrity of a soil can be altered by such activities as agriculture, silviculture, placement of fill, use of heavy equipment in construction projects, and surface mining. This variable is measured by determining if any of these activities have occurred on the site, and creating a weighted average of the scaled impacts in Table 6 by the area of the wetland assessment area covered by each alteration.

Table 6. Soil alteration categories and subindices.

Alteration Category	Effective Depth of Alteration	Variable Subindex
No Alteration	N/A	1.0
Agricultural Tillage: Some surface compaction occurs as well as decreasing the average size of the pore spaces; subsequently decreases the ability of water to move through the soil to about a depth of 6 in. (Drees et al. 1994).	top 6 in. of soil profile	0.5
Silviculture: Normal activities compact surface layers and reduce permeability to a depth of about 6 in. (Aust 1994)	top 6 in. of soil profile	0.5
Silviculture: Bedding activities compact surface layers, alter microtopography, reduce permeability to a depth of about 6-18 in.	top 6-18 in. of soil profile	0.3
Construction Activities: Compaction resulting from large equipment over the soil surface, cover of soil surface with pavement and fill material, or excavation and subsequent replacement of heterogeneous materials.	entire soil profile	0.1

Sites altered by agricultural (e.g. plowing and cultivation) or normal silvicultural activities (e.g., skidding, cutting or shearing) were assigned a variable subindex of 0.5. This is based on data from Aust (1994) and Drees et. al (1994), which indicate that the stated activities generally alter the top 6 in. of the soil profile and the lower 14 in. of the 20-in. profile is unaltered. Silvicultural bedding was assigned a 0.3, since changes to the microtopography of the site exacerbate the soils' ability to transport and retain water. Sites altered by construction activities or other activities that affect the entire 20-in. profile are assigned a subindex of 0.1 based on the fact that all soils, regardless of their permeability, reduce the velocity of water as it moves through the soil.

Hydrologic alterations ($V_{HYDROALT}$). This variable reflects alterations to the natural hydrology of the Headwater Slope wetland due to activities within the wetland boundary. Both natural and man-induced alterations can affect the hydrology of a Headwater Slope wetland. Examples in the reference domain include ditches, dams, road crossings, excavations and headcutting of water channels. The intent of this variable is to capture those impacts that alter the period of saturation or water storage capacity of the Headwater Slope wetland. This variable differs from V_{CATCH} and V_{UPUSE} in that the impacts occur within the wetland and not in the surrounding landscape. $V_{HYDROALT}$ applies only to the hydrology, biogeochemistry, and wildlife habitat functions.

The hydrology of unaltered Headwater Slope wetlands is dominated by groundwater, although in some reference standard sites shallow surface water may be present for short periods in early spring or after storm events. Under reference standard conditions (subindex = 1.0), there were no alterations to the natural hydrology of Headwater Slope wetlands. While surface water greater than 2.5 cm (1 in.) was not observed at any reference standard sites, there was evidence (drift lines, water marks) that surface water was as high as 8 cm (3 in.) for short periods. It is assumed that surface water 8 cm (3 in.) or less would receive a subindex score of 1.0. Impacts to the natural hydrologic regime are assumed to be proportional to the depth of surface water greater than 8 cm (3 in.) that could be retained in the wetland due to a dam or other structure (Figure 9), or to the depth of effective drainage due to ditches or other excavations within the wetland.

Figure 9. Water marks on trees are evidence of artificial ponding, in this case due to the blocking of water flow by a road.

Impacts that alter the storage capacity by 60 cm (24 in.) can alter the wetland to the extent that the hydrogeomorphic classification of the Headwater Slope wetland would change to a depressional or lacustrine fringe wetland, or the wetland could be drained to the extent that it would no longer have wetland hydrology. Impacts of this magnitude were assigned a subindex value of 0.0 (Figure 10). Some impacted sites in the reference domain had impounded water greater than 1 m (39 in.) deep.
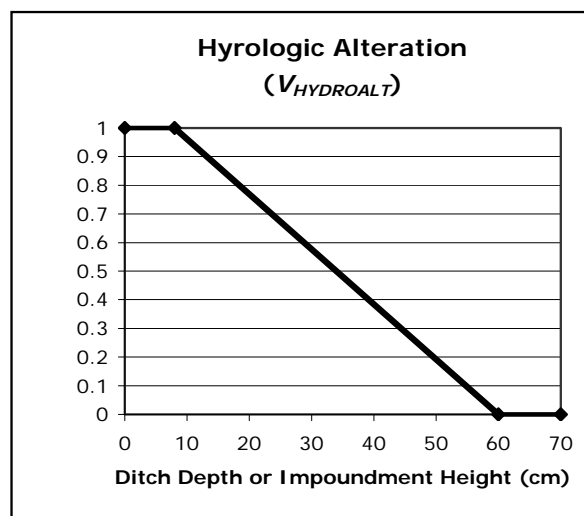
Figure 10. Relationship between depth or height of drainage or impoundment ($V_{HYDROALT}$) and functional capacity.

Canopy Tree Diameter (V_{CTD}).
This variable is the average diameter at breast height (dbh) of canopy trees measured at 1.4 m (55 in.) above the ground. This variable is only measured if percent tree cover is 20 percent or greater. Canopy trees are

defined as self-supporting woody plants ≥10 cm (4 in.) dbh, whose crowns comprise the uppermost stratum of the vegetation. Canopy trees are not immediately overtopped by taller trees and would be clearly seen by an airborne observer (Figure 11).
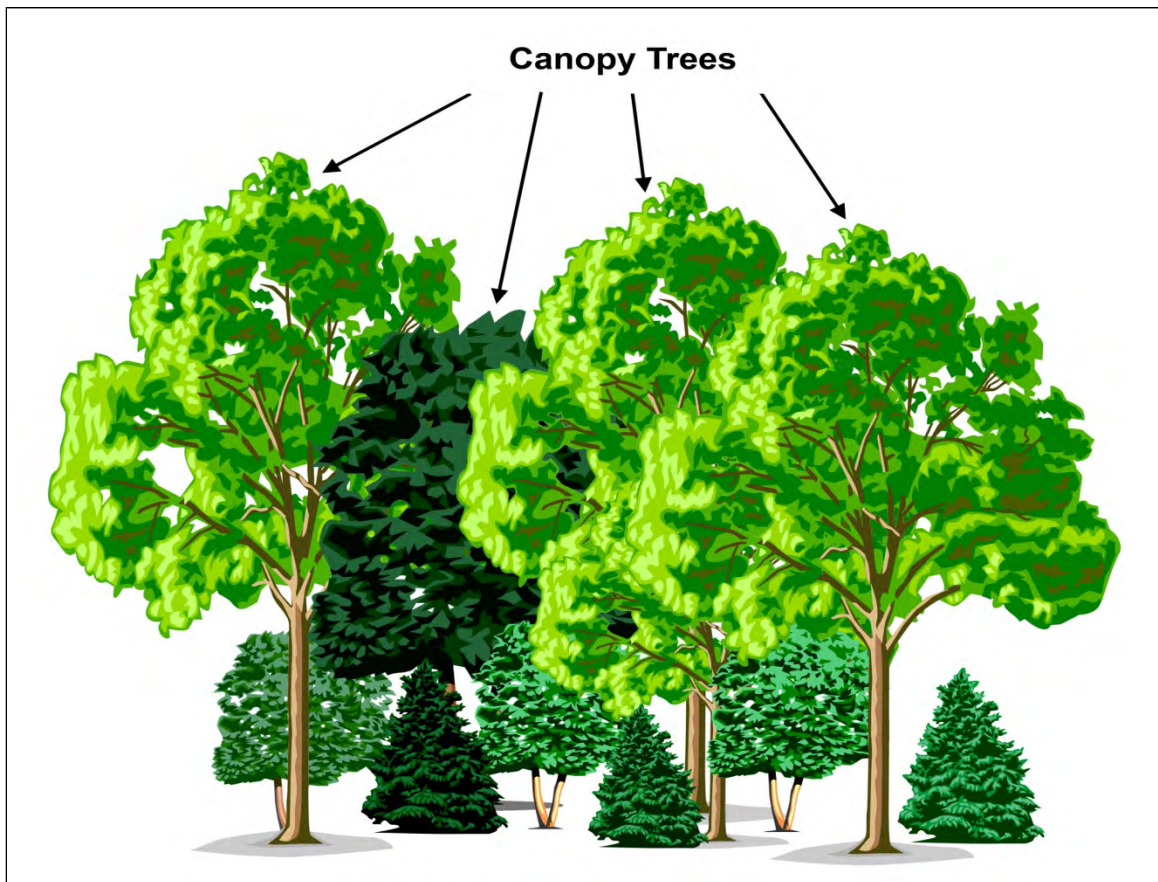
Figure 11. Example of canopy trees. Although not necessarily the tallest trees in a stand, canopy trees have no other tree foliage directly above them.

Tree diameter is a common measure of dominance in forest ecology, used either alone or in combination with tree density and basal area (Whittaker et al. 1974, Whittaker 1975, Spurr and Barnes 1980, Tritton and Hornbeck 1982, Bonham 1989). It expresses the relative age or maturity of a forest stand. V_{CTD} applies to all functions.

In Headwater Slope reference wetlands, the average dbh of canopy trees ranged from 0.0 cm on sites where all trees had been removed to 44 cm (17 in.) in mature forest stands. Based on data from reference standard sites, a variable subindex of 1.0 is assigned when mean dbh is ≥30 cm (12 in.) (Figure 12). A subindex value of 0.1 is assigned to severely altered sites where there is <20 percent canopy cover of trees and the tree stratum is not sampled. Therefore, mean dbh would be <10 cm. The relationship between canopy tree diameter and functional capacity of a Headwater Slope wetland is assumed to be linear; thus, the subindex increases linearly from 0.1 to reference standard values (Figure 12).
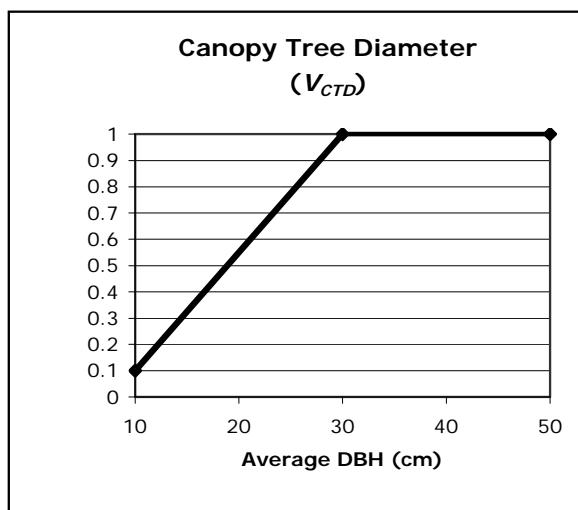
Figure 12. Relationship between average canopy tree diameter (V_{CTD}) at breast height and functional capacity.

Canopy Tree Density (V_{CTDEN}). This variable is defined as the density of canopy trees expressed as the number of tree stems per hectare. Canopy trees are defined as woody plants ≥10 cm (4 in.) dbh whose crowns comprise the uppermost stratum of the vegetation (see V_{CTD} above). Canopy trees are only measured if percent tree cover is 20 percent or greater. Tree density, in combination with average tree diameter, is a measure of the dominance and biomass of trees in a forest stand. V_{CTDEN} applies to all functions.

In South Carolina Headwater Slope reference wetlands, the average canopy tree density ranged from 0.0 stems/ha on sites where all trees had been removed to more than 1100 stems/ha in the densest stands. Based on data from reference standard sites, a subindex value of 1.0 is assigned when the density of canopy trees is between 250 and 650 stems/ha. A subindex value of 0.0 is assigned to severely altered
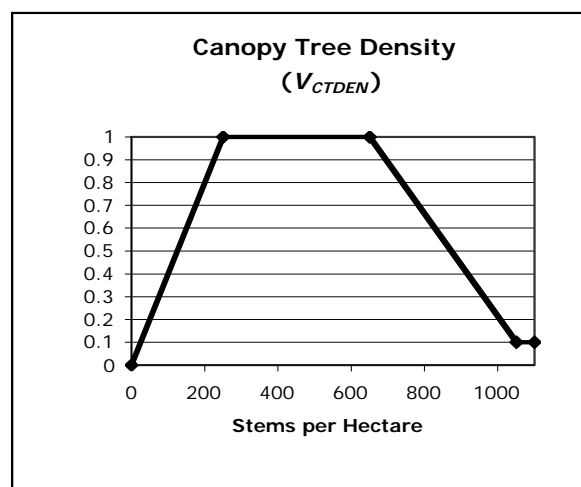
Figure 13. Relationship between average canopy tree density (V_{CTDEN}) and functional capacity.

sites that lack canopy trees and have density values of zero. At sites on which canopy tree density is between zero and the minimum reference standard value, the relationship between canopy tree density and the capacity to support characteristic wetland processes is assumed to be linear. During mid-successional stages, canopy tree density may exceed that in reference standard sites and it is assumed that characteristic processes will be adversely affected (Figure 13).

Sapling/shrub cover (V_{SSC}). This variable is defined as the average percent cover of woody vegetation >1 m (39 in.) in height and <10 cm (4 in.) dbh (e.g., shrubs, saplings, and understory trees). Shrubs contribute to the structure of the wetland plant community, particularly if trees are absent. They take up nutrients, produce biomass, and provide cover and breeding sites for wildlife. Shrubs may dominate the community in Headwater Slope wetlands during early to mid-successional stages. V_{SSC} applies only to the biogeochemistry, plant community, and wildlife habitat functions, and is only measured if tree canopy cover is <20 percent.

Sapling/shrub cover was highly variable in reference standard wetlands, ranging from 4 to 91 percent. However, V_{SSD} is not used to evaluate Headwater Slope wetlands that have a well-developed tree canopy. Instead, V_{SSD} is measured only in areas with <20 percent tree cover due to recent natural or anthropogenic disturbance. In this context, V_{SSD} reflects the amount of woody regeneration on the site that contributes immediately to carbon cycling and provides habitat for wildlife, and will eventually reproduce a mature forest canopy. Therefore, higher values of sapling/shrub cover are assumed to contribute more to these functions. Sapling/shrub cover on reference wetland sites with <20 percent tree cover ranged from 0 to 90 percent. Based on reference data, a subindex of 1.0 is assigned when sapling/shrub cover is $\geq$70 percent (Figure 14).
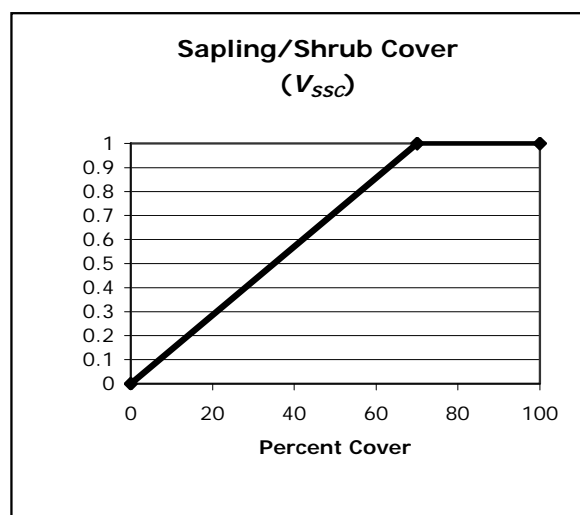
Figure 14. Relationship between average percent cover of saplings and shrubs (V_{SSC}) and functional capacity.

Ground Vegetation Cover (V_{GVC}). This variable is defined as the average percent cover of ground vegetation inside a 0.04-ha plot. Ground vegetation is defined as all herbaceous vegetation, regardless of height, and woody vegetation <1 m (39 in.) in height. Ground vegetation cover is an index to the abundance and biomass of low vegetation in Headwater Slope wetlands; the two characteristics affect the productivity and structure of these habitats. V_{GVC} only applies to the biogeochemistry, plant community, and wildlife habitat functions and only when canopy tree cover and shrub cover are each less than 20 percent.

On reference standard sites, coverage of ground-layer vegetation ranged from 78 to 91 percent. However, V_{GVC} is not used to evaluate Headwater Slope wetlands that have a well-developed tree or sapling/shrub canopy. Instead, V_{GVC} is measured only in areas where tree and sapling/shrub cover are both <20 percent due to severe natural or anthropogenic disturbance. Even under these conditions, ground-layer vegetation contributes some organic material to the wetland's carbon cycle, provides some benefits for wildlife, and helps produce conditions favorable to the regeneration of a woody midstory and canopy. Ground vegetation cover on reference sites with <20 percent tree and sapling/shrub cover ranged from 20 to 84 percent. A subindex of 1.0 is assigned when ground vegetation cover is ≥70 percent (Figure 15).
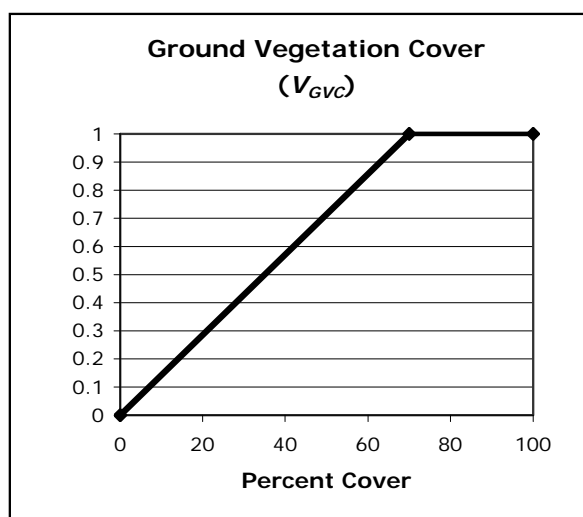
Figure 15. Relationship between average percent ground vegetation cover (V$_{GVC}$) and functional capacity.

Vegetation composition and diversity (V_{COMP}). This variable reflects the "floristic quality" of the community based on concepts in Andreas and Lichvar (1995) and Smith and Klimas (2002). The focus is on the plants that dominate the tallest stratum present. In reference standard Headwater Slope wetlands, the tallest stratum is composed of native canopy trees. In wetlands that have undergone recent and severe natural or anthropogenic disturbance, the tallest stratum may be dominated by herbaceous species or shrubs and tree saplings. Implicit in this approach is the assumption that the "quality" of the tallest layer is a good indicator of overall community

composition, both current and future (i.e., native tree species dominating the shrub/sapling layer indicate appropriate future canopy composition). Most reference standard wetlands within the reference domain are relatively diverse with several dominant species present. Dominant species are determined using the "50/20 rule" described in Figure 16. Note that the tree stratum includes all trees $\geq$10 cm (4 in.) dbh and not just "canopy" trees.

Dominant species are classified into three groups reflecting presumed floristic quality (Table 7). Group 1 consists of species that characterize undisturbed Headwater Slope wetlands in South Carolina. These include the various species of "bays," numerous hardwoods and pines that commonly dominate these communities, as well as swamp tupelo and baldcypress that can dominate in the wetter areas. Group 2 consists of other native plant species that are often present in Headwater Slope wetlands that have been disturbed or altered. Group 3 consists of non-native (exotic) species or native invasive species that are usually found on highly degraded sites.

In reference standard Headwater Slope wetlands within the reference domain, dominant vegetation composition included species from Groups 1 and 2, and the number of dominants was 4 or greater. As either composition or richness deviates from those conditions, functional capacity is assumed to decline. The procedure used to calculate a subindex value for V_{COMP} is described in Chapter 5 and incorporates both richness and quality of dominant species. V_{COMP} applies only to the plant community function.

Steps in the 50/20 Rule for Designating Dominant Plant Species:

1. Apply this procedure only to the tallest stratum present. To count as present, the total cover of the tree and sapling/shrub strata must be $\geq$20 percent.
2. Estimate the absolute percent cover of each species in the tallest stratum.
3. Rank all species in the stratum from most to least abundant.
4. Calculate the total coverage for all species in the stratum (i.e., sum their individual percent cover estimates). Absolute cover estimates do not necessarily sum to 100%.
5. Select plant species from the ranked list, in decreasing order of coverage, until the cumulative coverage of selected species exceeds 50% of the total coverage for the stratum. The selected species are all considered to be dominants. All dominants must be identified to species.
6. In addition, select any other species that, by itself, is at least 20% of the total percent cover in the stratum. Any such species is also considered to be a dominant and must be identified accurately.

Figure 16. Description of the 50/20 rule.

Table 7. Quality Scores for Dominant Plant Species
Used to Calculate V_{COMP}.

Scientific Name[1]	Common Name	Score
Group 1		
Acer rubrum	red maple	1.0
Carya cordiformis	bitternut hickory	
Fraxinus caroliniana	Carolina ash	
Fraxinus pennsylvanica	green ash	
Fraxinus profunda	pumpkin ash	
Magnolia grandiflora	southern magnolia	
Magnolia virginiana	sweetbay	
Nyssa aquatica	water tupelo	
Nyssa sylvatica	blackgum	
Nyssa sylvatica var. *biflora*	swamp tupelo	
Persea borbonia	redbay	
Pinus glabra	spruce pine	
Pinus taeda	loblolly pine	
Quercus laurifolia	laurel oak	
Quercus michauxii	swamp chestnut oak	
Quercus nigra	water oak	
Quercus pagoda	cherrybark oak	
Quercus phellos	willow oak	
Taxodium distichum	baldcpress	
Ulmus americana	American elm	
Group 2[2]		
Carpinus caroliniana	American hornbeam	0.66
Celtis laevigata	sugarberry	
Cornus foemina	stiff dogwood	
Diospyros virginiana	persimmon	
Ilex opaca	American holly	
Liquidambar styraciflua	sweetgum	
Liriodendron tulipifera	tuliptree	
Group 3[3]		
Albizia julibrissin	Silktree	0.0
Alternanthera philoxeroides	Alligatorweed	
Arundo donax	Giant Reed	
Cyperus iria	Ricefield flatsedge	
Echinochloa crus-galli	Barnyard grass	

Scientific Name[1]	Common Name	Score
Group 3[3] (continued)		
Imperata cylindrica	Cogongrass	
Ligustrum japonicum	Japanese privet	
Ligustrum sinense	Chinese Privet	
Lonicera japonica	Japanese Honeysuckle	
Lygodium japonicum	Japanese Climbing Fern	
Microstegium vimineum	Nepalese Browntop	
Panicum repens	Torpedo grass	
Pueraria montana	Kudzu	
Sorghum halepense	Johnsongrass	
Triadica sebifera	Tallowtree	
Verbena brasiliensis	Brazilian Vervain	
[1] Plant names according to the USDA Plants database (http://plants.usda.gov/).		
[2] Other native plant species may be added to Group 2.		
[3] Other non-native or invasive plant species may be added to Group 3.		

Soil Detritus ($V_{DETRITUS}$). This variable consists of the percent cover of detrital material on the soil surface. Soil detrital material is defined as the soil layer dominated by partially decomposed but still recognizable organic material, such as leaves, sticks, needles, flowers, fruits, insect frass, dead moss, or detached lichens on the surface of the ground. This material would classify as fibric or hemic material (peat or mucky peat). Detritus is a direct indication of short-term (one or two years) accumulation of organic matter primarily from vegetation within the wetland. $V_{DETRITUS}$ applies only to the biogeochemistry function.

The cover of soil detritus in South Carolina Headwater Slope reference wetlands ranged from 0 to 100 percent. Based on data from reference standard wetland sites, a variable subindex of 1.0 is assigned when detrital cover is between 97 and 100 percent (Figure 17). The main reasons that detrital cover is reduced or absent are reduced tree cover and increased water flow across the headwater wetland. Increased water flow washes detritus down gradient. Sites lacking detritus are assigned a subindex of 0.0. A linear increase in the subindex score as detrital cover increases from 0 to 97 percent is assumed (Figure 18).

Figure 17. View of Headwater Slope wetland showing 100 percent cover of soil detritus.

Surface Soil Organic Matter (V_{SSOM}). Surface soil organic matter is defined as the amount of organic matter present in the surface soils (upper 6 in.), immediately below the detrital layer, if present. Soil organic matter is the result of long-term (at least several years) accumulation due to the decomposition of the detrital layer by microorganisms and incorporation into the soil. Direct measurement of the percentage of organic matter in the soil is not practical for a rapid assessment. A relative determination of the soil organic matter content can be made using soil color "value," part of the Munsell system of color notation. Darker (i.e., lower value) colors indicate
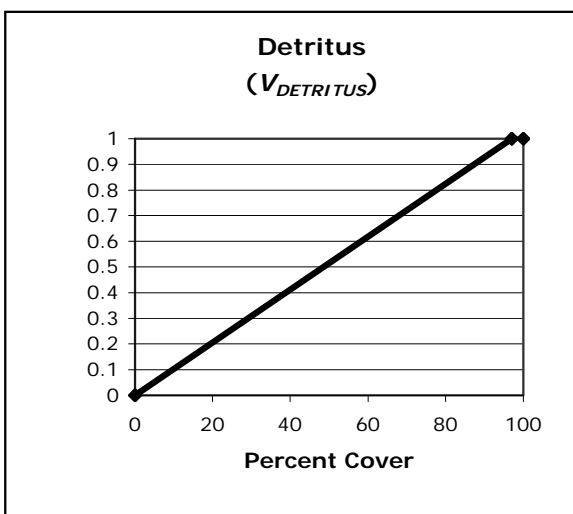
Figure 18. Relationship between average percent cover of detritus ($V_{DETRITUS}$) and functional capacity.

higher amounts of soil organic carbon. V_{SSOM} applies only to the biogeochemistry function.

In Headwater Slope reference wetlands, Munsell soil color values ranged from 2 to 7. Based on data from reference standard sites, a variable subindex of 1.0 is assigned to wetland sites with average soil color values of 2.5 or less (see Appendix B). Average Munsell soil color values greater than 6.5 in the surface layer indicate a very low percentage of organic matter and severely altered conditions. These sites are assigned a subindex of 0.0. The rate at which the subindex decreases is based on the assumption that the relationship between color value and biogeochemical processes in Headwater Slope wetlands is linear (Table 8).

Table 8. Relationship between surface soil color
value and functional capacity.

Munsell Soil Color Value	Subindex Score
Less than or equal to 2.5	1.0
Greater than 2.5, but less than or equal to 3.5	0.8
Greater than 3.5, but less than or equal to 4.5	0.6
Greater than 4.5, but less than or equal to 5.5	0.4
Greater than 5.5, but less than or equal to 6.5	0.2
Greater than 6.5, but less than or equal to 10	0.0

Woody Debris Biomass (V_{WD}). This variable represents the total mass of organic matter contained in woody debris on or near the surface of the ground. Woody debris is an important habitat and nutrient cycling component of forests. Woody debris is defined as down and dead woody stems that are greater than 0.25 in. in diameter that are no longer attached to living plants. Despite its relatively slow turnover rate, woody debris is an important component of food webs and nutrient cycles of temperate terrestrial forests (Harmon et al. 1986). In the context of this function, this variable serves as an indicator that the nutrients in vegetative organic matter are being recycled.

Volume of woody debris per hectare is used to quantify this variable. Woody debris is measured with a procedure adapted from Brown (1974) and Brown et al. (1982). Two transects are randomly placed in the sampling plot. Along each, stems that intersect the vertical plane of the transect are measured as follows: stems that are between 0.25 and 1.0 in.

in diameter are counted along a 6-ft section of the 50-ft transect; stems that are between 1.0 and 3 in. in diameter are counted along a 12-ft section of the 50-ft transect; and stems greater than 3-in. diameter are measured along the entire 50-ft transect. These counts and measurements are converted using the data spreadsheet or by hand using the formula in Appendix B. Woody debris is reported in m³/ha.

In South Carolina reference wetlands, the volume of woody debris ranged from 0 to 496 m³/ha. Based on data from reference standard sites, a variable subindex of 1.0 is assigned to sites with woody debris ranging from 30 to 160 m³/ha (Figure 19). Below 30 m³/ha, the variable subindex linearly decreases to 0.0. The decrease in the variable subindex is based on the assumption that lower volumes of woody debris indicate an inadequate reservoir of nutrients and the inability to maintain characteristic nutrient cycling over the long term.
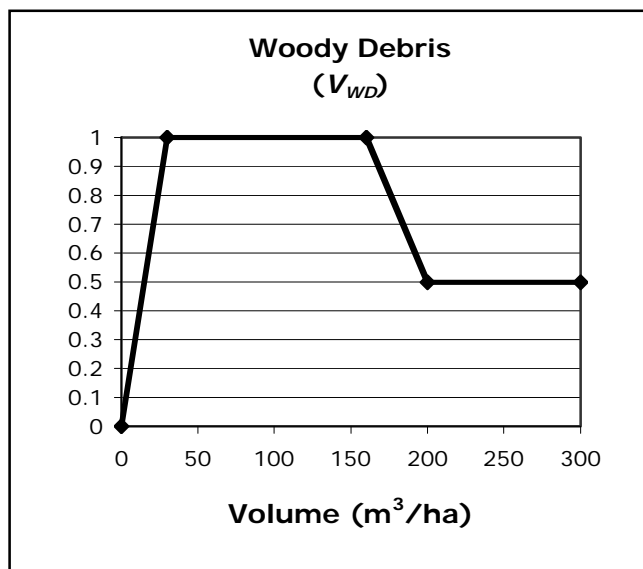
Figure 19. Relationship between woody debris and functional capacity.

Above 160 m³/ha, the variable subindex decreases linearly to 0.5 at 200 m³/ha. This is based on the assumption that increasingly higher volumes of woody debris indicate that high levels of nutrients are tied up in long-term storage and are unavailable for primary production in the short term. This situation can occur in instances of catastrophic wind damage, such as hurricanes. It can also occur if a hydrologic obstruction increases inundation depth or duration to the point that trees experience tip dieback or death. This situation can also occur following logging operations.

Functions

The following sequence is used to present and discuss each function:

    a. *Definition:* Defines the function.

    b. *Rationale for selecting the function*: Provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.

    c. *Characteristics and processes that influence the function*: Describes the characteristics and processes of the wetland and the surrounding landscape that influence the function and lay the groundwork for the description of model variables.

    d. *Functional capacity index*: Describes the assessment model from which the functional capacity index is derived and discusses how model variables interact to influence functional capacity.

Function 1: Water Storage

Definition

The Water Storage function is defined as the capacity of the Headwater Slope wetland to store water within the soil for a few days to a few weeks and slowly release this water to down-slope wetlands or streams. A potential independent, quantitative measure for validating the function is a direct measurement of the amount of water that is dynamically stored within the wetland over a portion of the year.

Rationale for selecting the function

The annual water budget of Headwater Slope wetlands is controlled mainly by interception of the groundwater table and secondarily by precipitation and upland runoff. Performance of the Water Storage function causes the wetland to retain subsurface water inputs for a sufficient period of time to develop other wetland characteristics (e.g., hydric soils, hydrophytic vegetation). Storage also alters the amount and timing of runoff from a catchment into streams, reducing the pulse of runoff that occurs following a storm event and prolonging the period of discharge into streams. In South Carolina, the principal source of water for short-term storage in headwater wetlands is discharge of groundwater from the surrounding uplands. Loss of water that has been dynamically stored occurs mainly through evapotranspiration, runoff, or subsurface flow. The rate of groundwater movement is controlled by the hydraulic conductivity of the soil.

Water storage has a significant effect on elemental cycling in the wetland. Prolonged saturation leads to anaerobic soil conditions and initiates chemical reactions that are highly dependent upon the redox capacity of the soil (Mausbach and Richardson 1994). The oxygen concentration in wetland soils greatly affects the redox potential and the chemical cycling properties of elements and compounds, particularly nutrients. This function also has important impacts on invertebrate and vertebrate

populations. For example, some invertebrates, such as midges, have very rapid life cycles and are highly adapted to ephemeral wetlands.

Characteristics and processes that influence the function

The characteristics and processes that influence the capacity of a headwater wetland to store water have both natural and anthropogenic origins. Climate, landscape-scale geomorphic characteristics, and characteristics of the soil within and around the wetland are factors largely established by natural processes. Anthropogenic alterations of a wetland (e.g., tilling, cattle grazing, logging) also influence the way a wetland stores surface water (Figure 20). Such effects may take the form of the dominant land use in and near the wetland and whether the wetland has been hydrologically modified through ditching or damming.

In the Coastal Plain of South Carolina, rain is fairly evenly distributed throughout the year. Summer thunderstorms are common and tropical storms and hurricanes occasionally affect the area. Surface soil saturation can occur during any month and, in some wetlands, is evident all year. In others, saturation to the surface is most evident in late winter and early spring before trees have completely leafed out.

Figure 20. Logging of Headwater Slope wetlands not only alters the vegetative community, but drastically changes the hydrologic regime, natural biogeochemical processes, and wildlife habitat.

Soil properties of Headwater Slope wetlands are highly variable. Some soils in the reference domain are very sandy and have high hydraulic conductivities. In contrast, some Headwater Slope wetlands contain clay loam or organic-textured soils that restrict hydraulic conductivity, slowing the release of stored water. Therefore, the duration of water storage in headwater wetlands in the reference domain varies.

In addition to geomorphic and climatic processes, human activities may also have a profound effect on the storage of water within a slope wetland. Modifications to the uplands surrounding the wetland or directly to the wetland itself may affect the receipt and retention of water. Soil compaction, cultivation, road construction, urban development, grazing or logging directly affect this function. Many headwater wetlands and the lands surrounding them are either grazed or cultivated.

Ditching or tiling for the purpose of draining a wetland (e.g., to put it into crop or timber production) and damming a wetland to provide stormwater retention have modified many headwater wetlands. Such modifications so significantly affect the natural short-term water storage of the headwater wetland that many such wetlands lose their natural wetland characteristics and may change HGM wetland subclass or class, or no longer meet the definition of a wetland at all.

Functional Capacity Index

The following variables are used in the assessment model for the Water Storage function:

- Hydrologic Alterations ($V_{HYDROALT}$)
- Change in Catchment Size (V_{CATCH})
- Upland Land Use (V_{UPUSE})
- Soil Integrity ($V_{SOILINT}$)
- Canopy Tree Diameter (V_{CTD})
- Canopy Tree Density (V_{CTDEN})

The assessment model for calculating the functional capacity index (FCI) for Water Storage is as follows (Equation 3):

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{CATCH} + V_{UPUSE} + V_{SOILINT}}{3} \right) + \left(\frac{V_{CTD} + V_{CTDEN}}{2} \right)}{2} \right]^{\frac{1}{2}} \right\} \quad (3)$$

In this model (Equation 3), the Water Storage capacity of Headwater Slope wetlands depends on inputs of water from groundwater and runoff from the surrounding upland, and the ability of that water to flow through the wetland soil. Water is removed from the system in surface and subsurface outflow and evapotranspiration. The model assumes that, if natural hydrologic inputs from groundwater and runoff from the surrounding uplands are unaltered, and outflow is not increased by drainage ditches, soil compaction or headcutting, or blocked by artificial obstructions such as dams, and a mature forest is present to remove water through evapotranspiration at characteristic rates, then the wetland is functioning at reference standard condition.

This model addresses three main factors that influence wetland Water Storage. The first term of the equation reflects alterations to the wetland ($V_{HYDROALT}$) that affect its capacity to store groundwater for short periods. However, storage of atypically large amounts of surface water due to impoundment results in a decrease in FCI. The second term of the equation averages two sets of factors. The first includes variables affecting the supply of water from the surrounding uplands (V_{CATCH} and V_{UPUSE}) through runoff and shallow groundwater flow, as well as the ability of water to flow through the soil ($V_{SOILINT}$). The second includes variables that remove water from the wetland via evapotranspiration by mature tree canopy (V_{CTD} and V_{CTDEN}).

The final two terms of the equation are combined using a geometric mean based on the assumption that $V_{HYDROALT}$ is as important as the combination of the other variables in relation to Water Storage. In other words, if the wetland is drained to the point that it no longer has wetland hydrology, or to the point that it ponds water and has been changed from a Headwater Slope wetland to a depressional or lacustrine fringe system, then the subindex score for $V_{HYDROALT}$ would be 0.0 and the functional capacity for Water Storage would be zero as well.

If the cover of the tree canopy is less than 20%, the term that includes the characteristics of the tree strata in Equation 3 is reduced to 0, and the rest of the equation remains the same. Thus, if a site has been logged, but other variables affecting the Water Storage function are compatible with reference standard conditions, the maximum FCI a site could achieve would be 0.71.

Function 2: Cycle Organic Carbon

Definition

The Cycle Organic Carbon function is defined as the ability of the wetland to retain and transform inorganic materials needed for biological processes into organic forms and to oxidize those organic molecules back into elemental forms through decomposition. Thus, organic carbon cycling includes the biogeochemical processes of producers, consumers, and decomposers. Potential independent, quantitative measures that may be used in validating the functional index include direct measurements of net annual productivity (gm/m^2), annual accumulation of organic matter (gm/m^2), and annual decomposition of organic matter (gm/m^2).

Rationale for selecting the function

Organic carbon cycling is a fundamental function performed by all ecosystems, but tends to be accomplished at particularly high rates in many wetland systems (Mitsch and Gosselink 2000). A sustained supply of organic carbon in the soil provides for maintenance of the characteristic plant community including annual primary productivity, composition, and diversity (Bormann and Likens 1970, Whittaker 1975, Perry 1994). The plant community (producers) provides the food and habitat structure (energy and materials) needed to maintain the characteristic animal community (consumers) (Crow and MacDonald 1978, Fredrickson 1978, Wharton et al. 1982). In time, the plant and animal communities serve as a source of detritus that is the source of energy and materials needed to maintain the characteristic community of decomposers. The decomposers break down these organic materials into simpler elements and compounds that can reenter the nutrient cycle (Reiners 1972, Dickinson and Pugh 1974, Pugh and Dickinson 1974, Schlesinger 1977, Singh and Gupta 1977, Hayes 1979, Harmon et al. 1986, Vogt et al. 1986).

Characteristics and processes that influence the function

Organic carbon cycling is a function of biotic and abiotic processes that result from conditions within and around the wetland. In wetlands, carbon is stored within, and cycled among, four major compartments: (a) the soil, (b) primary producers such as vascular and nonvascular plants, (c) consumers such as animals, fungi, and bacteria, and (d) dead organic matter, such as leaf litter or woody debris, referred to as detritus. Organic carbon cycling is probably best known through plants and the processes of

photosynthesis and respiration. Oxygen is needed for respiration, and the rate of diffusion of oxygen in water is 1/10,000[th] of that in air. Wetland plants, called hydrophytes, are unique in that they have adapted to living in water or wet soil environments. Physiological adaptations in leaves, stems, and roots allow for greater gas exchange, permit respiration to take place, and allow the plant to harvest the stored chemical energy it has produced through photosynthesis. Although there is no clear starting or ending point for carbon cycling, it can be argued that it is the presence and duration of water in the wetland that determines the characteristic plant community of hydrophytes. In turn, it is the maintenance of the characteristic primary productivity of the plant community that sets the stage for all subsequent transformations of energy and materials at each trophic level within the wetland. It follows that alterations to hydrologic inputs, outputs, or storage and/or changes to the characteristic plant community will directly affect the way in which the wetland can perform this function.

Abiotic processes affecting retention and cycling of carbon are dependent primarily on the adsorption of materials to soil particles, the amount of water that passes through the wetland carrying dissolved carbon, the hydroperiod or retention time of water that maintains anaerobic conditions, and the importation of materials from surrounding areas (Grubb and Ryder 1972, Federico 1977, Beaulac and Reckhow 1982, Ostry 1982, Shahan 1982, Strecker et al. 1992, Zarbock et al. 1994). Natural soils, hydrology, and vegetation are important factors in maintaining these characteristic processes.

The ability of a Headwater Slope wetland to perform this function depends upon the transfer of carbon between trophic levels within the wetland, the rate of decomposition, and the flux of materials in and out of the wetland. A change in the ability of one trophic level to process carbon will result in changes in the processing of carbon in other trophic levels (Carpenter 1988).

The ideal approach for assessing carbon cycling in a headwater wetland would be to measure the rate at which carbon is transferred and transformed between and within trophic levels over several years. However, the time and effort required to make these measurements are well beyond a rapid assessment procedure. Reference data suggest that land-use practices and current treatments within the wetland have great effect on the characteristic plant community structure (species composition and

coverage), diversity, and primary productivity. Changes in the vegetative cover directly affect the amount of organic carbon present in the wetland. Canopy removal in particular directly affects the amount and type of detritus present in the headwater wetland. Changes in the amount of woody debris alter the long-term stores of organic material ready for movement to the soils, whereas changes in the amount of smaller detritus alter short-term stores organic material. Soil color value is an indicator of cation exchange capacity and, therefore, indicates long-term carbon and nutrient supply and a characteristic decomposer community. Changes in hydrology or vegetation, deposition of fill material, excavation, or recent fire can alter the amount of soil detritus or soil organic matter. Soil alterations also change the features to which native plants are adapted. Changes to the hydrology of headwater wetlands through drainage, increased surface water flow, or ponding have a tremendous effect on carbon cycling. Increased surface water flow can sweep detrital matter from the wetland and disrupt the carbon cycle. Drainage increases the rate of decomposition of soil organic matter and, over time, changes the vegetative composition and, therefore, the type and amount of detrital matter. Ponding reduces the rate of decomposition and increases the accumulation of organic carbon, as well as changing the vegetative community. It is assumed that measurements of these characteristics reflect the level of carbon cycling taking place within a wetland.

Functional capacity index

The following variables are used in the assessment model for the Cycle Organic Carbon function:

- Hydrologic Alterations ($V_{HYDROALT}$)
- Soil Detritus ($V_{DETRITUS}$)
- Surface Soil Organic Matter Content (V_{SSOM})
- Canopy Tree Diameter (V_{CTD})
- Canopy Tree Density (V_{CTDEN})
- Sapling/Shrub Cover (V_{SSC}) (This variable is used only if total tree canopy cover is <20 percent)
- Ground Vegetation Cover (V_{GVC}) (This variable is used only if both tree and sapling/shrub cover are <20 percent)
- Woody Debris (V_{WD})

The assessment models for calculating the functional capacity index (FCI) for the Cycle Organic Carbon function in Headwater Slope wetlands are

given below. The models depend, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer (≥20% total tree cover), then Equation 4 is used. If dominated by saplings and shrubs (<20% canopy cover of trees but ≥20% cover of saplings and shrubs), then Equation 5 is used. If neither trees nor saplings/shrubs are common (<20% cover), then Equation 6 is used.

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{WD} + V_{DETRITUS} + V_{SSOM}}{3}\right) + \left(\frac{V_{CTD} + V_{CTDEN}}{2}\right)}{2} \right]^{1/2} \right\} \quad (4)$$

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{WD} + V_{DETRITUS} + V_{SSOM}}{3}\right) + V_{SSC}}{3} \right]^{1/2} \right\} \quad (5)$$

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{WD} + V_{DETRITUS} + V_{SSOM}}{3}\right) + V_{GVC}}{5} \right]^{1/2} \right\} \quad (6)$$

In these models, changes in the organic carbon cycling capacity of Headwater Slope wetlands relative to reference standard conditions depend on three terms in the equation. The first represents increased outflow of water, or on reductions in water inflows, or changes in hydroperiod. The second term represents non-living trophic compartments for organic carbon: long-term storage in downed woody debris, shorter-term stores in detritus, and decomposed soil organic matter. The third term represents living biomass, with variables depending on the most mature strata onsite. The models are based on the assumption that if normal amounts of carbon occur in non-living ecosystem compartments — the soil, detrital layer, and down woody debris — and in living compartments in the form of vegetation, and anthropogenic hydrologic disturbance is not present in the wetland, then carbon cycling is occurring at an appropriate rate. In the first part of each equation, removal or retention of surface water is represented by $V_{HYDROALT}$. In the second part, V_{WD} represents long-term stores of organic matter available for decomposition over months (for small branches) or

years (for logs). This will likely be low in young stands where single tree replacement has not yet started, and may be high in sites with perturbations — wind, long-term inundation, or logging — causing tip dieback or death to trees. $V_{DETRITUS}$ is used as an indicator of recent organic input and accumulation. If vegetation has been removed from the wetland during the previous year or two, then the amount of detritus will likely be reduced or absent. Also, if the hydrology of the wetland or adjacent watershed has been altered to the point that detritus is being flushed from the headwater ecosystem, then this alteration should be reflected in the amount of detrital cover. Surface Soil Organic Matter (V_{SSOM}) is an indication of long-term organic matter accumulation and incorporation into the soil. If hydrology or vegetation have been altered for more than a few years, then the color of the surface soil will be lighter, reflecting a decrease in organic matter content. Also, if fill material has been placed in the wetland or if soil excavation has taken place, the organic matter in the previous soil surface will have been disturbed. These three variables, $V_{DETRITUS}$, V_{WD}, and V_{SSOM}, are combined using an arithmetic mean. This is based on the assumption they are of equal importance in cycling organic carbon. Headwater wetland vegetation is represented by the combination of V_{CTD} and V_{CTDEN}, sapling/shrub cover (V_{SSC}), or ground vegetative cover (V_{GVC}), whichever is representative of the tallest stratum within the headwater wetland or WAA. If the amount of vegetation, represented by percent cover, is reduced, then it is assumed that cycling organic carbon will be reduced. In contrast, if the amount of vegetation is greater than that found under the reference standard conditions, then abnormal amounts of carbon may accumulate in the wetland and the FCI is reduced. In Equation 4, the groundcover, soils, and vegetative parts of the equations are averaged. In Equations 5 and 6, the two parts are divided by factors of 3 and 5, respectively, to reflect the assumption that sites dominated by sapling/shrubs or ground vegetation do not produce or Cycle Organic Carbon at the same rate as a mature forest. For a sapling/shrub-dominated wetland, the maximum FCI is 0.82. For a wetland lacking both tree and sapling/shrub strata, the maximum FCI is 0.63.

The two parts of the model are combined using a geometric mean. The implications are that if all of the variables in any part of the model equal zero, then the function would receive an FCI of zero.

Function 3: Maintain a Characteristic Plant Community

Definition

This function is defined as the degree to which a Headwater Slope wetland supports a plant community that is similar in structure and composition to that found on the least disturbed sites in the reference domain. Potential independent, quantitative measures of this function, based on species composition and relative abundance, include similarity indices (Ludwig and Reynolds 1988) or ordination axis scores from detrended correspondence analysis or other multivariate techniques (Kent and Coker 1995). An alternative, independent, quantitative measure of this function, based on composition and abundance as well as environmental factors, is ordination axis scores from canonical correlation analysis (ter Braak 1994).

Rationale for selecting the function

The ability to Maintain a Characteristic Plant Community is important in part because of the intrinsic value of the species found there. In the Coastal Plain landscape, the dominant community type is pine flatwoods, and the Headwater Slope wetland subclass constitutes a small percentage of the overall area. Because many plant species do not occur in other landforms, their maintenance and abundance are linked to the subclass. The presence of a characteristic plant community also is critical in maintaining various biotic and abiotic processes occurring in wetlands. For example, plant communities are the source of primary productivity, produce carbon and nutrients that may be exported to other ecosystems, and provide habitats and refugia necessary for various animal species (Harris and Gosselink 1990).

Overview of the plant community

The plant communities of Headwater Slope wetlands are complex and vary locally and across the Coastal Plain landscape. Except immediately following severe disturbances, forest is the dominant community type in the subclass. Sites that have been relatively undisturbed for decades or centuries are composed of trees of various sizes and ages and generally predictable species composition. Depending on the species that initially occupy a site after a major disturbance, succession can progress along different paths, but because of small-scale disturbances (e.g., individual trees dying and creating canopy gaps that may be colonized by different species), eventually an uneven-aged forest with well-developed stratification

will be achieved (Hunter 1990). In general, older stands tend to be more stratified than younger stands and forests with several vertical strata have higher species diversity than young or middle-aged stands with few strata (Willson 1974, Hunter 1990). This is important in maintenance of the community over time, given that diversity has been found to be positively related to community stability (Bolen and Robinson 2003).

Sites that have escaped significant disturbance for long periods normally will be dominated by trees in the larger diameter (dbh) classes. Brower and Zar (1984) noted that tree basal area (and, by inference, tree dbh) is positively correlated with stand maturity and is an indicator of time since significant disturbance (fire, catastrophic storm damage, harvest, etc.). U.S. Forest Service (1980) and Burns and Honkala (1990) are good sources of information on the maximum size that individual species of trees can attain. For many species that can occupy the overstory in Headwater Slope wetlands, older trees may reach 80 cm to more than 200 cm in diameter.

Tree density is a characteristic of forest ecosystems that varies considerably throughout the life of an individual stand. In most forested systems, the density of tree seedlings and saplings is very high following stand establishment and decreases as the forest matures and the crowns grow together to form the canopy (Spurr and Barnes 1980). Stem densities often number in the tens of thousands per hectare in the early stages of succession and normally will be reduced to a few hundred per hectare at maturity.

Within the Coastal Plain of South Carolina, several forest communities may dominate a reference standard Headwater Slope wetland. At the headward extent, when there are infrequent, low-intensity fires, regular soil moisture, and few channels removing water, the vegetation becomes dominated by "bays" including sweetbay (*Magnolia virginiana*), southern magnolia (*M. grandiflora*), red bay (aka, swamp bay) (*Persea borbonia*) in the overstory or midstory (Monk 1966, Nelson 1986, Wharton et al. 1977, U. S. Army Corps of Engineers 1988). These Headwater Slope wetland forests have been described (often referred to as bayheads) as having dense canopies and tangled midstories and understories of tall shrubs and vines (Wharton et al. 1977, Nelson 1986). Braun (1950) stated that "pine and sweet bay flats with their dense tangle of shrubs and lianas, interrupt the longleaf pine (*Pinus palustris*) woods." Nelson (1986) noted that bayheads sometimes have exposed and highly convoluted roots near the surface. Wharton et al. (1977)

described the herbaceous understory as sparse while other authors, including Monk (1966) and Nelson (1986), listed numerous species that occur in the lower strata. U.S. Army Corps of Engineers (1988) did not mention herbaceous understory species in that account.

The Society of American Foresters (Eyre 1980) recognizes a "Sweetbay-Swamp Tupelo (*Nyssa sylvatica* var. *biflora*)-Redbay" forest type (Type 104) that is found on moist to wet sites in "branch heads; the narrow bottoms of small perennial or intermittent streams or branches; pocosins; and poorly drained upland depressions in the Coastal Plain" and "the borders of swamps" from Maryland and southeastern Virginia to southeastern Texas. Species composition is described as highly variable and associated species include red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), loblolly-bay, water oak (*Quercus nigra*), baldcypress (*Taxodium distichum*), slash pine (*Pinus elliottii*), evergreen shrubs, ferns, pitcher plants (*Sarracenia* spp.), and sedges.

In the wettest portions of the subclass, where several branches of headwater slopes converge but any channels present are still inefficient at carrying away flow, vegetation can transition to dominance by bald cypress (*Taxodium distichum)*, water tupelo *(Nyssa aquatica)*, and swamp tupelo (*Nyssa biflora*). However, bald cypress is sometimes absent from these sites due to past logging. Green ash (*Fraxinus pennsylvanica*), Carolina ash (*F. caroliniana*), pumpkin ash (*F. profunda*), red maple (*Acer rubrum*), American elm (*Ulmus americana*) and laurel oak (*Quercus laurifolia*) are commonly found in the overstory (NatureServe 2002).

In topographic high points within the wetland or within transitions to uplands, soil inundation is less frequent, with shorter or irregular hydroperiods and more xeric summertime conditions. In these areas, forests tend to be dominated by willow oak (*Quercus phellos*), cherrybark oak (*Q. pagoda*), swamp chestnut oak (*Q. michauxii*), bitternut hickory (*Carya cordiformis*), spruce pine (*Pinus glabra*), and loblolly pine (*Pinus taeda*). Other floodplain oaks and sweetgum (*Liquidambar styraciflua*) may occur. American hornbeam (*Carpinus caroliniana*) and American holly (*Ilex opaca*) can dominate the well-developed subcanopy stratum (NatureServe 2002).

Shrub species similarly are diverse and include wax myrtle (*Morella cerifera*), Virginia willow (*Itea virginica*), fetterbush (*Lyonia lucida*),

possumhaw (*Viburnum nudum)*, and large gallberry (*Ilex coriacea*). Azalea (*Rhododendron canescens*) was not mentioned as a dominant in previous studies, but is common in the understory of Headwater Slope wetlands in the Coastal Plain of South Carolina.

Herbaceous species and vines that occur commonly in the understory include various ferns (e.g., Virginia chain fern (*Woodwardia virginica*), cinnamon fern (*Osmundo cinnamomea*), and netted chain fern (*Woodwardia areolata*).) Woody vines that sometimes are abundant include muscadine (*Vitis rotundifolia*), laurel-leafed greenbriar (*Smilax laurifolia*), and poison ivy (*Toxicodendron radicans*). Royal fern (*O. regalis*) and various orchids (*Platanthera* spp.) were not mentioned in previous studies, but are common in some Headwater Slope wetlands in the Coastal Plain of South Carolina.

The plant communities of Headwater Slope wetlands have been described by most authors as having a dense canopy with a tangled midstory and understory of tall shrubs and vines (Wharton et al. 1977, Nelson 1986). Braun (1950) stated that "pine and sweet bay flats with their dense tangle of shrubs and lianas interrupt the longleaf pine (*Pinus palustris*) woods." Most authors -- including Monk (1966), Gemborys and Hodgkins (1971), and Nelson (1986) — described the understory as dense and listed numerous species that occur in the lower strata. Wharton et al. (1977), however, described the herbaceous understory of bayheads as sparse. Nelson (1986) noted that bayheads sometimes have exposed highly convoluted roots near the surface.

Factors that influence the plant community

Factors that influence the development and maintenance of a characteristic plant community in most wetlands (including Headwater Slope wetlands in the Coastal Plain) include the physical site characteristics, the hydrologic regime, fire frequency and intensity, weather events, anthropogenetic disturbances, and various ecological processes such as competition, disease, browsing pressure, shade tolerance, and community succession. Alteration to these factors or processes in the wetland or to the landscape surrounding a wetland may directly affect the species composition and biodiversity of the site (Askins et al. 1987, Keller et al. 1993, Kilgo et al. 1997). Much of the descriptive work on plant communities of forested wetlands (and factors that influence their development and maintenance) was done in riverine systems (Robertson et al. 1978, Wharton et al. 1982, Robertson 1992,

Messina and Conner 1997), and less information is available regarding Headwater Slope wetlands. It is logical to infer, however, that excepting the significant differences in hydrologic inputs and processes, many of the factors that influence forested wetlands in general also are important in this subclass. These factors are well-documented in Mitsch and Gosselink (2000) and in HGM guidebooks for riverine wetlands in western Kentucky (Ainslie et al. 1999) and peninsular Florida (Uranowski et al. 2003).

An appropriate hydroperiod is one of the most important factors necessary for the development and maintenance of a characteristic plant community. In Headwater Slope wetlands, water delivery occurs as direct precipitation, overland flow, or groundwater discharge from the surrounding uplands (see Function 1). Groundwater discharge is believed to be the most important of the three in the maintenance of wetland hydrology. Activities that degrade the physical nature of a wetland, especially its hydroperiod, have the potential to have deleterious effects on the plant community and may alter the plant community for extended periods, and even permanently. For example, depositing fill in a wetland fundamentally changes the substrate and hydrologic regime and will likely result in conversion of the area from wetland to non-wetland. If the site is allowed to re-vegetate, the ensuing plant community probably will be composed of different species, including those with less tolerance for wetness (i.e., facultative, facultative upland and upland plants as categorized by Reed (1988)).

Some alterations that occur outside of the wetlands may have serious negative consequences for the plant community. For example, clearing the natural vegetation in the upland watershed or adding impervious surfaces (roads, parking lots, etc.) can lead to significantly more water entering a wetland, resulting in a community dominated by more flood-tolerant species, such as baldcypress or water tupelo. If mean water depths increase beyond the ability of these species to survive, the area would become an open water basin with vegetation existing at the edges.

Two studies relevant to the subclass, Gemborys and Hodgkins (1971) and Nelson (1986), described the effects of forestry practices on the plant community. Gemborys and Hodgkins (1971) noted that timber extraction, particularly of slash pine and tulip poplar, occurs in headwater wetlands in southern Alabama and foresters sometimes institute management practices that favor these two species. Nelson (1986) reported that the

logging of bay trees for pulpwood has the potential to alter the structure and composition of bayhead wetlands in South Carolina.

Invasion by exotics such as Chinese privet (*Ligustrum sinense*) or tallowtree (*Triadica sebifera*) can result in changes in the species composition of Headwater Slope wetlands, particularly in the lower strata.[1] Several invasive exotics including Japanese honeysuckle (*Lonicera japonica*), silktree (*Albizia julibrissin*), and kudzu (*Pueraria montana*) are present in the reference domain and have the potential to impact plant community composition and diversity.

Except for anthropogenic impacts, Headwater Slope wetlands in the reference domain are influenced primarily by small-scale disturbances, primarily individual tree mortality, which leads to gap-phase regeneration. Fire, the primary large-scale disturbance mechanism in the reference domain, does not occur frequently in the wetlands themselves due to the moist environment. Forests that develop under such conditions are generally composed of shade-tolerant species of different age (and by inference size) classes (Hunter 1990).

Fire, which does periodically occur in Headwater Slope wetlands and can play a role in shaping the plant community. Wharton et al. (1977) stated that "bay forests are thought to succeed from Atlantic white cedar swamps and from "gum ponds" in the absence of fire and subsequent invasion by additional hardwood species." U.S. Army Corps of Engineers (1988) noted similar relationships between white cedar and bay swamps in Florida. Monk (1966, 1968) believed that bayheads are climax communities and may be "preceded (in succession) by pond pine or cypress wetlands." Fire intensity (as opposed to frequency) may be the primary factor that influences the interactions between these two communities. Wharton et al. (1977) stated that severe fires may result in bay forests reverting to Atlantic white cedar, but the role that fire plays in the dynamics between these communities is complex. The most comprehensive summary of white cedar swamps (Laderman 1989), noted that stands of cedar may be destroyed by intense fire, but "light" fire reduces competition and permits cedar reproduction. Clewell (1971) noted that bays have the ability to sprout from top-killed stumps; consequently, they have adapted to fires that at occasionally burn through headwater wetlands.

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[1] Personal communication. 2003. C. Henderson, Mississippi Department of Marine Resources, Biloxi, MS.

One way of evaluating the extent of a disturbance to a Headwater Slope wetland is to determine the "floristic quality" of the dominant species in the plant community following the process of Andreas and Lichvar (1995). Their approach essentially integrates many influencing factors such as hydrology and soil properties, successional patterns, and disturbance. They assign different rankings to taxa present based on the degree of their fidelity to synecological parameters. Plants found in many communities -- including disturbed sites — were assigned rankings of 1 − 3. Plants associated with communities that tolerate moderate disturbance were assigned rankings of 4 − 6. Plants associated with advanced successional stages that have undergone relatively minor disturbance were assigned rankings of 7 − 8. Plants with a high degree of fidelity to a narrow range of synecological parameters were assigned values of 9 − 10. The latter two categories typically will comprise species that are tolerant to very tolerant of shade (i.e., they can persist in the understory and thus can "capture" gaps in the canopy when they occur). In the reference domain, common dominants in Headwater Slope wetlands that are shade tolerant include red bay, red maple, and laurel oak (Burns and Honkala 1990). Older stands in which little disturbance has occurred likely will include one or more of these species as dominant canopy trees.

Functional capacity index

The following variables are used in the assessment model to Maintain a Characteristic Plant Community function:

- Canopy Tree Diameter (V_{CTD})
- Canopy Tree Density (V_{CTDEN})
- Vegetation Composition and Diversity (V_{COMP})
- Sapling/Shrub Cover (V_{SSC}) (This variable is used only if total tree canopy cover is <20 percent.)
- Ground Vegetation Cover (V_{GVC}) (This variable is used only if tree and sapling/shrub cover are both <20 percent.)

The assessment models for calculating the FCI for the maintenance of a characteristic plant community in Headwater Slope wetlands are given below. The model used depends on the characteristics of the uppermost stratum of vegetation present within the wetland. If the site contains a tree layer ($\geq$20% total tree cover), then Equation 7 is used. If dominated by saplings and shrubs (<20% cover of trees but $\geq$20% cover of saplings and

shrubs), then Equation 8 is used. If neither trees nor saplings/shrubs are common (<20% cover), then Equation 9 is used.

$$FCI = \left(\frac{\dfrac{V_{CTD} + V_{CTDEN}}{2} + V_{COMP}}{2} \right) \tag{7}$$

$$FCI = \left(\frac{V_{SSC} + V_{COMP}}{4} \right) \tag{8}$$

$$FCI = \left(\frac{V_{GVC} + V_{COMP}}{6} \right) \tag{9}$$

These models represent the existing plant community in the wetland and include variables that provide insight into its seral stage, structure, species composition, diversity, and stability. The models assume that the physical environment necessary to maintain the community (e.g., hydrology, soil characteristics) is also present. If not, any recent environmental changes that may affect the long-term persistence of the community should be reflected in reduced FCIs for Functions 1 and 2. In the context of this function, canopy tree diameter (V_{CTD}) and density (V_{CTDEN}) are structural indicators of seral stage and of disturbance. The vegetation composition and diversity variable (V_{COMP}) reflects floristic quality and diversity, as well as seral stage and disturbance. In a forested wetland (Equation 7), subindices for V_{CTD} and V_{CTDEN} are averaged before being combined with V_{COMP}. V_{CTD} and V_{CTDEN} cannot go to 0.0 if trees are present; therefore, the FCI will always be greater than zero if trees are present. In Equations 8 and 9, the two variables are divided by a factor of 4 or 6, respectively, under the assumption that sites dominated by saplings/shrubs or ground vegetation do not provide the level of function provided by a mature forest community, even if succession will tend toward that condition eventually. For a sapling/shrub-dominated wetland, the maximum FCI is 0.50. For a wetland lacking both tree and sapling/shrub strata, the maximum FCI is 0.33.

Function 4: Provide Characteristic Wildlife Habitat

Definition

This function is defined as the capacity of a Headwater Slope wetland to provide critical life requisites to selected components of the vertebrate

wildlife community. Wetlands within the subclass provide habitat for numerous species of amphibians, reptiles, birds, and mammals. Birds and amphibians were selected as the focus of this function. Birds were chosen because they are of public and agency interest, and they respond rapidly to changes in the quality and quantity of their habitats. In addition, bird species have strong associations with the different strata of the multi-layered forests that characterize reference standard Headwater Slope wetlands. Birds have been shown to be sensitive indicators and integrators of environmental change such as that brought about by human use and alteration of landscapes (Morrison 1986, Croonquist and Brooks 1991, O'Connell et al. 2000). Amphibians were chosen because of the importance of wetlands as breeding habitat. Various species of salamanders and frogs breed in shallow streams, temporary ponds, and moist leaf litter or duff. In the adult stages, they often disperse into suitable habitat in the adjacent uplands.

A potential independent, quantitative measure of this function that could be used to validate the assessment model (Wakeley and Smith 2001) is the combined species richness of birds and amphibians that use Headwater Slope wetlands throughout the annual cycle. Data requirements for model validation include direct monitoring of wildlife communities using appropriate techniques for each taxon. Ralph et al. (1993) described field methods for monitoring bird populations. Gibbons and Semlitsch (1981) described procedures for sampling small animals, including reptiles and amphibians. Heyer et al. (1994) and Dodd (2003) described monitoring procedures for amphibians.

Rationale for selecting the function

Wetlands are recognized as valuable habitats for a diversity of animal species including both vertebrates and invertebrates. For example, songbirds, such as the prothonotary warbler (*Protonotaria citrea*) and Acadian flycatcher (*Empidonax virescens*), are associated with forested wetlands within the reference domain and provide recreational opportunities for birdwatchers and nature enthusiasts. Further, because birds are highly mobile, they serve as a transfer mechanism for nutrients and energy from wetlands to other ecosystems. Several mammals, including the mink (*Mustela vison*) and raccoon (*Procyon lotor*), also are closely associated with wetlands and similar environments. They are important predators in wetlands and riparian areas and, as such, play key roles in ecosystem structure and stability. Amphibians are common in

most wetland ecosystems, but many are secretive and seldom seen. In some situations, they can be extremely abundant. Burton and Likens (1975) reported that amphibians constitute the single largest source of vertebrate biomass in some ecosystems. Because many amphibians require both wetland and adjacent upland habitats, they serve as a conduit for energy exchange between the two systems (Mitchell et al. 2004). Wharton et al. (1982), Johnson (1987), Whitlock et al. (1994), Crowley et al. (1996), Mitsch and Gosselink (2000), and Bailey et al. (2004) are all good sources of information regarding animal communities of wetlands.

Many wildlife species associated with wetlands have experienced serious population declines. Within the United States, approximately one third of the plant and animal species listed as threatened or endangered are associated with wetlands during some part of their life cycle (Dahl and Johnson 1991). Headwater Slope wetlands constitute a relatively small percentage of the landscape within the reference domain, and the upland matrix in many areas is dominated by agricultural land, managed forests, and residential and commercial development. Therefore, Headwater Slope wetlands are likely important for the maintenance of local populations of many species.

Overview of the wildlife community

Within the reference domain, numerous game and non-game species from four vertebrate classes commonly use Headwater Slope wetlands for shelter, as breeding or foraging areas, or as sources of drinking water. This general discussion includes information about reptiles and mammals although, as noted previously, birds and amphibians are the focus of the wildlife model.

Avian species use Headwater Slope wetlands throughout the year, although some species are present only periodically. Common year-round residents include: the Carolina chickadee (*Poecile carolinensis*), tufted titmouse (*Baeolophus bicolor*), Carolina wren (*Thryothorus ludovicianus*), blue-gray gnatcatcher (*Polioptila caerulea*), blue jay (*Cyanocitta cristata*), northern cardinal (*Cardinalis cardinalis*), and red-bellied woodpecker (*Melanerpes carolinus*). Species such as the great crested flycatcher (*Myiarchus crinitus*), eastern wood-peewee (*Contopus virens*), Kentucky warbler (*Oporornis formosus*), and summer tanager (*Piranga rubra*) breed in wetlands within the subclass, but winter primarily in tropical areas. Other species do not breed in the reference domain, but winter there and may use

Headwater Slope wetlands during that period. Some examples include the yellow-bellied sapsucker (*Sphyrapicus varius*), ruby-crowned kinglet (*Regulus calendula*), black-and-white warbler (*Mniotilta varia*), and the yellow-rumped warbler (*Dendroica coronata*). During the spring and fall migration periods, numerous species of neotropical migrants use Headwater Slope wetlands as "stopover" habitat. Wharton et al. (1982), Hamel (1992), and Boynton (1994) contain information about avian communities in Southeastern wetlands.

Bailey et al. (2004) described the habitats important to amphibians and reptiles and their management in the Southeast. Some of the species they considered characteristic of springs and seepage areas (the habitat type they described that is most like Headwater Slope wetlands) included the spotted dusky salamander (*Desmognathus conanti*), southern two-lined salamander (*Eurycea cirrigera*), green frog (*Rana clamitans*), southern leopard frog (*R. sphenocephala*), southern water snake (*Nerodia fasciata*), and queen snake (*Natrix septemvittata*). See Mount (1975) and Conant and Collins (1991) for additional information about amphibians and reptiles in the reference domain.

Several mammals routinely use Headwater Slope wetlands within the reference domain. Some species (or their sign) were observed during the development of this guidebook. These included the raccoon, eastern cottontail rabbit (*Sylvilagus floridanus*), gray squirrel (*Sciurus carolinensis*), and white-tailed deer (*Odocoileus virginianus*). These and many other species of medium- to large-sized mammals that occur in the reference domain (e.g., mink, opossum (*Didelphis marsupialis*), and gray fox (*Urocyon cinereoargenteus*)) likely use Headwater Slope wetlands as foraging sites or as sources of drinking water. The mink and raccoon, especially, are known to be associated with wetland habitats. Several chiropterans, including the red bat (*Lasiurus borealis*) and evening bat (*Nycticeius humeralis*), occur within the reference domain and favor wetlands as foraging habitat.[1] Small mammals such as mice, voles, and shrews often use a variety of habitats, of which two, the golden mouse (*Ochrotomys nuttalli*) and southeastern shrew (*Sorex longirostris*), tend to be associated with wetlands within reference domain (Kays and Wilson 2002).

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[1] Roberts, T. 2004. Personal communication with M. J. Harvey. June. Tennessee Technical University, Cookeville, TN.

Characteristics and processes that influence the function

Hydrologic alteration of Headwater Slope wetlands has the potential to impact a number of wildlife species, but the most serious impacts would be to amphibians. Animals with direct dependence on water, such as amphibians that use seasonally ponded micro-depressions within Headwater Slope wetlands for reproduction, are highly vulnerable to wetland drainage (e.g., by ditching) or filling of wetlands for development. Even partial draining or filling could impact breeding activity because of the length of time needed for egg development and maturation of the young. There is considerable variability in development time among species. Most anurans require the presence of water for 2-3 months (Duellman and Trueb 1986). Some species, however, require substantially shorter periods of time. The eastern spadefoot toad (*Scaphiopus holbrooki holbrooki*), for example, needs only 2-3 weeks to mature.[1] Conversely, artificially increasing the amount of time that surface water is present in a wetland by excavating or augmenting runoff into the wetland can potentially reduce the suitability for amphibians by allowing fish populations to become established. Bailey et al. (2004) noted that predatory fish prey on breeding amphibians, their eggs, and tadpoles. They recommended that wherever wetlands free of fish exist, efforts should be made to avoid accidental or deliberate introductions.

Besides the direct effects of hydrologic change on animals, indirect effects can occur through changes in the plant community. Sites with unaltered hydrology that have not been subjected to significant disturbance for long periods support a characteristic vegetation composition and structure (i.e., tree size, density, stratification, etc.) as described in the plant community model. Wildlife species have evolved with and adapted to these conditions. Thus, altering the plant community has the potential to change the composition and structure of the wildlife community. Other factors including droughts and catastrophic storms, fire frequency and intensity, competition, disease, browsing pressure, shade tolerance, community succession, and natural and anthropogenic disturbances also affect the wildlife community indirectly. Following is an overview of the relationships between specific characteristics of the plant community and wildlife utilization of forested ecosystems including wetlands. Wharton et al. (1982), Hunter (1990), and Morrison et al. (1992) are all good sources of information on this subject.

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[1] Roberts, T. 2004. Personal communication with M. A. Bailey. June. Conservation Southeast, Inc., Andalusia, AL.

Habitat structure is probably the most important determinant of wildlife species composition and diversity (Wiens 1969, Anderson and Shugart 1974). This is especially well-documented with birds, which tend to show affinities for habitats based on physical characteristics, such as the size and density of overstory trees, density of shrub and ground cover, number of snags, and other factors. MacArthur and MacArthur (1961) documented the positive relationship between the vertical distribution of foliage (i.e., the presence of different layers or strata) and avian diversity. Other researchers have since corroborated their findings. For example, Ford's (1990) study of birds and their habitats in bottomland hardwood wetlands supported the importance of community structure to the majority of species that were common at his study sites during the breeding season. Many of these same species also occur in Headwater Slope wetlands within the reference domain. Hunter (1990) provided a good overview of the importance of plant community structure to wildlife.

Undisturbed Headwater Slope wetlands within the reference domain contain multiple strata. Structural complexity provides a myriad of habitat conditions for animals and allows numerous species to coexist in the same area (Schoener 1986). For example, some bird species utilize the forest canopy, whereas others are associated with the understory (Cody 1985, Wakeley and Roberts 1996). Structural characteristics of forested ecosystems (e.g., tree size, tree density, and understory cover) are easily measured and are reliable indicators of habitat quality for birds. Similar measures of vegetation structure have been used in Habitat Suitability Index (HSI) models (Schroeder 1985, Allen 1987) and in other HGM guidebooks (Ainslie et al. 1999, Smith and Klimas 2002). They are discussed briefly in the following paragraphs.

Tree size is an indicator of forest maturity (Brower and Zar 1984, DeGraaf et al. 1992) and, in most cases, structural complexity (Hunter 1990). Older, undisturbed Headwater Slope wetlands dominated by large trees provide resources that areas dominated by smaller trees cannot. For example, large trees are more likely to develop natural cavities or be attacked by cavity excavators. Cavities provide shelter and nesting sites for gray squirrels, red-bellied woodpeckers, and other species. In forests populated by oaks, age is an important factor in acorn production. Although there is considerable variation among species, most oaks do not begin producing acorns until they are at least 25 cm (10 in.) in diameter (U.S. Forest Service 1980). Older forests dominated by large trees also typically have distinct strata, including

a tree canopy, a woody understory composed of saplings and shrubs, and a herbaceous or ground layer. Young forests composed of sapling to pole-sized trees tend to be less stratified.

Tree density also is an indicator of forest maturity. In most forested systems, the density of tree seedlings and saplings is very high following stand establishment and decreases as the forest matures (Spurr and Barnes 1980, Hunter 1990, DeGraaf et al. 1992). Stem densities often number in the tens of thousands per hectare in the early stages of succession and normally are reduced to a few hundred per hectare at maturity. In undisturbed mature forested wetlands within the reference domain, tree spacing is such that the crowns grow relatively close together. Reducing tree density, such as through timber harvesting, reduces crown volume and results in a direct loss of fruit production and foraging space for insectivorous birds. Canopy cover also affects the lower strata by controlling the amount of sunlight that reaches the forest floor. Generally, there is an inverse relationship between canopy cover and understory density (Hunter 1990).

A well-developed sapling/shrub layer (i.e., woody stems <10 cm (4 in.) dbh) is present in most undisturbed Headwater Slope wetlands and has a significant influence on the wildlife community. Bird species that are closely associated with the sapling/shrub layer include the northern cardinal, Carolina wren, brown thrasher (*Toxostoma rufum*), white-eyed vireo (*Vireo griseus*), Kentucky warbler, and hooded warbler (*Wilsonia citrina*). Roberts and Peterson (2001) found both bird abundance and species richness to be positively correlated with percent shrub cover in depression and flat wetlands in central Tennessee. It is likely that a similar relationship exists for wetlands in the Headwater Slope subclass.

Land use surrounding the wetland also has a major impact on the wetland wildlife community. Historically, the reference domain was largely forested. The wildlife community evolved in a landscape with wetlands surrounded by vast tracts of open woods and savannas maintained by frequent fires. With fire suppression during recent times, many upland forests on the Coastal Plain have become more crowded with undergrowth and increasingly dominated by hardwoods.

Human activities have dramatically altered the reference domain in other ways as well. Currently much of it is devoted to commercial pine planta-

tions, crop production and pasture, residential and commercial developments, and other "open" land uses. Consequently, Headwater Slope wetlands often occur as isolated patches within an open landscape matrix. Adverse effects of the "fragmentation" of formerly forested landscapes have been well-documented for avian species and communities (Askins et al. 1987, Keller et al. 1993, Kilgo et al. 1997) and for reptiles and amphibians (Laan and Verboon 1990, Semlitsch 1998, Semlitsch and Jensen 2001, Rothermel and Semlitsch 2002, Bailey et al. 2004). Research into the effects of fragmentation on mammals has been less common (Nilon 1986, VanDruff and Rowse 1986, Nilon and VanDruff 1987).

Biological and genetic diversity are reduced as habitat fragmentation and urbanization occur in an area. Larger and more specialized animal species, especially those having large home ranges, are affected from the onset of fragmentation (VanDruff et al. 1996). Habitat specialists are often the first to be extirpated from an area or region. Eventually, even generalist species are impacted if fragmentation is extreme. Urbanization often accompanies habitat fragmentation. Urbanization reduces the number of native wildlife species in an area, while increasing the abundance of exotic species (VanDruff et al. 1996, McKinney 2002).

Although tied to wetlands and other aquatic habitats for breeding, many southeastern frogs and some salamanders spend portions of the year in terrestrial habitats, often in hardwood forests (Mitchell et al. 2004). Semlitsch and Jensen (2001) noted that suitable terrestrial habitat surrounding breeding sites is critical for feeding, growth, maturation, and maintenance of populations of pond-breeding salamanders. Bailey et al. (2004) concurred, stating that "a seasonal wetland without appropriate surrounding upland habitat will lose its amphibian and reptile fauna." Semlitsch and Jensen (2001) suggested that the terrestrial habitat be referred to as part of the "core habitat" used by the animals. This is different from the traditional concept of the "buffer zone" commonly recommended around wetlands to protect various wetland functions (Boyd 2001).

Semlitsch and Bodie (2003) reviewed the literature on terrestrial habitats used by amphibians. Habitat features such as leaf litter, coarse woody debris (i.e., logs), boulders, small mammal burrows, cracks in rocks, spring seeps, and rocky pools were important for foraging, refuge, or over-wintering. A well-developed canopy (for shade) and coarse woody debris and litter (for refuge and food) were considered to be essential habitat

features. The abundance of litter is related to the age of forest stands. The litter layer in an older forest is usually thicker than in a younger forest due to the amount of foliage produced. Young stands do not begin to contain large amounts of litter and coarse woody debris until natural thinning begins. Coffey (1998) reported that minimal woody debris was found in bottomland hardwood stands younger than 6 years of age. Such a pattern also exists in upland forests. Shade, which is critical to amphibian species in slowing or preventing dehydration (Spight 1968, Rothermel and Semlitsch 2002), is provided to some extent in all forest stands but likely is not effective until tree canopies begin to close (Rothermel and Semlitsch 2002). Managed pine forest is considered suitable amphibian habitat only if soils, litter, and ground-layer vegetation have not been disturbed extensively (e.g., by bedding) such that cover has been eliminated and animal movement impeded. Areas devoted to row crops and closely mowed or grazed pastures are not suitable (Boyd 2001).

In addition to the structural characteristics of contiguous habitats, the size of such areas is also important to many amphibian and reptile species. The width of suitable contiguous habitat needed for any given wetland area depends upon a number of variables, including wetland size, topography, climate, surrounding land use, and the species of herpetofauna present (Semlitsch and Jensen 2001). Boyd (2001) compiled information regarding animal use of areas adjacent to wetlands. She concluded that 30-m (100-ft) buffer provided protection for 77% of the species known to be dependent on wetlands, but recommended that even larger areas be considered because numerous species sometimes travel much greater distances. Semlitsch and Bodie (2003) synthesized the literature on terrestrial habitats used by amphibians and reptiles associated with wetlands and concluded that core terrestrial habitat extends 159-290 m (522-950 ft) from the wetland edge for most amphibians and 127-289 m (417-948 ft) for most reptiles, although some species may move much farther. For example, certain frogs sometimes move up to 1,600 m (5,250 ft) from the aquatic edge. The mean maximum distances moved (calculated from numerous studies of various herpetofauna) included 218 m (715 ft) for salamanders, 368 m (1,207 ft) for frogs, 304 m (997 ft) for snakes, and 287 m (942 ft) for turtles.

Terrestrial areas immediately adjacent to wetlands are important to the integrity of the wetland ecosystem. Such areas reduce the amounts of silt, contaminants, and pathogens that enter the wetland, and moderate physical parameters such as temperature (Rhode et al. 1980, Young et al. 1980,

Hupp et al. 1993, Snyder et al. 1995, Daniels and Gilliam 1996, Semlitsch and Jensen 2001, Semlitsch and Bodie 2003). These functions directly or indirectly affect amphibians through improved water quality and provide benefits to the entire wildlife community. Semlitsch and Bodie (2003) recommended a 30- to 60-m (100- to 200-ft) wide "buffer" around the wetland for this purpose.

Birds are impacted adversely by habitat fragmentation due to increased predation, nest parasitism by the brown-headed cowbird (*Molothrus ater*), and other factors (Askins et al. 1987, Keller et al. 1993, Kilgo et al. 1997). Species have lower reproductive output in smaller habitat patches or avoid small patches altogether.[1] While landscape considerations are important for birds as well as amphibians, there is a substantial difference in scale, with patch size requirements for some individual bird species exceeding 5,000 ha (12,355 ac). Given the current land use and small size of most Headwater Slope wetlands within the reference domain, focusing the landscape-level variables in the model entirely on birds is impractical. Although having sufficient core habitat for amphibians may not entirely eliminate adverse effects of fragmentation, it should be useful in protecting birds from nest parasitism and predation by animals. Most impacts on birds are thought to occur relatively close to an edge (within 100-300 m (328-984 ft)) (Brittingham and Temple 1983, Strelke and Dickson 1980, Wilcove 1985).

Functional Capacity Index

The following variables are used in the assessment model for the Provide Characteristic Wildlife Habitat function:

- Hydrologic Alterations ($V_{HYDROALT}$)
- Change in Catchment Size (V_{CATCH})
- Upland Land Use (V_{UPUSE})
- Canopy Tree Diameter (V_{CTD})
- Canopy Tree Density (V_{CTDEN})
- Habitat Connections ($V_{CONNECT}$)
- Sapling/Shrub Cover (V_{SSC}) (This variable is used only if total tree cover is <20 percent.)

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[1] Roberts, T. 2004. Personal communication. with D. A. Buehler. June. University of Tennessee, Knoxville, TN.

- Ground Vegetation Cover (V_{GVC}) (This variable is used only if tree and sapling/shrub cover are both <20 percent.)
- Woody Debris Biomass (V_{WD})

The model chosen for deriving the functional capacity index for the characteristic wildlife habitat function of Headwater Slope wetlands depends, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer ($\geq$20% total tree cover), then Equation 10 is used. If dominated by saplings and shrubs (<20% cover of trees but $\geq$20% cover of saplings and shrubs), then Equation 11 is used. If neither trees nor saplings/shrubs are common (<20% cover), then Equation 12 is used.

$$FCI = \left[\left(V_{HYDROALT} \times \left\{ \frac{V_{CATCH} + V_{UPUSE}}{2} \right\} \right)^{\frac{1}{2}} \times \left(\frac{\left\{ \frac{V_{CTD} + V_{CTDEN} + V_{WD}}{3} \right\} + V_{CONNECT}}{2} \right) \right]^{\frac{1}{2}} \quad (10)$$

$$FCI = \left[\left(V_{HYDROALT} \times \left\{ \frac{V_{CATCH} + V_{UPUSE}}{2} \right\} \right)^{\frac{1}{2}} \times \left(\frac{\left\{ \frac{V_{SSC} + V_{WD}}{2} \right\} + V_{CONNECT}}{5} \right) \right]^{\frac{1}{2}} \quad (11)$$

$$FCI = \left[\left(V_{HYDROALT} \times \left\{ \frac{V_{CATCH} + V_{UPUSE}}{2} \right\} \right)^{\frac{1}{2}} \times \left(\frac{\left\{ \frac{V_{GVC} + V_{WD}}{2} \right\} + V_{CONNECT}}{10} \right) \right]^{\frac{1}{2}} \quad (12)$$

This model is assumed to reflect the ability of Headwater Slope wetlands to provide critical life requisites for wildlife, with an emphasis on amphibians and birds. If the components of this model are similar to those found under reference standard conditions, then it is likely that the entire complement of amphibians and birds characteristic of Headwater Slope wetlands within the reference domain will be present.

The first part of each equation is an expression of the hydrologic integrity of the wetland and involves variables $V_{HYDROALT}$, V_{CATCH}, and V_{UPUSE}. In the context of this function, a characteristic hydrologic regime is a source of

water for breeding amphibians and to support plant and animal communities. The second part of each equation reflects seral stage, cover potential, food production potential, nest site potential, availability of dispersal habitat, and other factors that depend on stand structure, maturity, and connectivity. V_{CTD} and V_{CTDEN} are used when the wetland is dominated by trees; V_{SSC} is used in sapling/shrub-dominated wetlands; and V_{GVC} is used in wetlands lacking sufficient trees or shrubs. Woody debris is also an important habitat criteria for amphibians and birds. Other features of forested wetlands such as snags and leaf litter are also important habitat requirements for various members of the wildlife community, but are not explicitly included in the model. It was assumed that if the structure and composition of the overstory and shrub layer and woody debris are appropriate, then these additional features will be present in the appropriate numbers or amounts. The final variable in each equation is $V_{CONNECT}$, which represents the availability of suitable habitat beyond the wetland boundary. This terrestrial buffer helps protect wetland water quality, provides critical habitat for some species of amphibians, and is important in protecting birds from nest predators and parasites. Hydrologic integrity is assumed to be critical to the maintenance of wetland wildlife habitat; therefore, the hydrology component is used as a multiplier in each equation. The other terms in the model, which reflect onsite and offsite habitat conditions, are assumed to be partially compensatory (i.e., a low value for one term will be partially compensated by a high value for the other(s)). In Headwater Slope wetlands dominated by trees, the maximum possible FCI is 1.0. Wetlands dominated by saplings and shrubs and few or no large trees are assumed to have lower value for birds and amphibians; the maximum FCI in sapling/shrub wetlands is 0.63. In wetlands containing few trees or shrubs, the maximum FCI is 0.45.

5   Assessment Protocol

Introduction

Previous chapters of this Regional Guidebook provide background information on the HGM Approach, and document the variables, measures, and models used to assess the functions of Headwater Slope wetlands. This chapter outlines a protocol for collecting and analyzing the data necessary to assess the functional capacity of a wetland in the context of a Section 404 permit review or similar assessment scenario. The typical assessment scenario is a comparison of preproject and postproject conditions in the wetland. In practical terms, this translates into an assessment of the functional capacity of the WAA under both preproject and postproject conditions and the subsequent determination of how FCIs have changed as a result of the project. Data for the preproject assessment are collected under existing conditions at the project site, while data for the postproject assessment are normally based on the conditions expected to exist following proposed project impacts. A skeptical, conservative, and well-documented approach is required when defining postproject conditions. This recommendation is based on the often-observed lack of similarity between predicted or engineered postproject conditions and actual postproject conditions. This chapter discusses each of the following tasks required to complete an assessment of Headwater Slope wetlands:

a. Define assessment objectives
b. Characterize the project area
c. Screen for red flags
d. Define the wetland assessment area
e. Determine the wetland subclass
f. Collect the data
g. Analyze the data
h. Apply assessment results

Define assessment objectives

Begin the assessment process by unambiguously identifying the purpose of the assessment. This can be as simple as stating, "The purpose of this assessment is to determine how the proposed project will impact wetland functions." Other potential objectives could be as follows:

a. Compare several wetlands as part of an alternatives analysis.
b. Identify specific actions that can be taken to minimize project impacts.
c. Document baseline conditions at a wetland site.
d. Determine mitigation requirements.
e. Determine mitigation success.
f. Determine the effects of a wetland management technique.

Frequently, multiple reasons are identified for conducting an assessment. Carefully defining the purpose(s) facilitates communication and understanding among the people involved in the assessment, and makes the goals of the study clear to other interested parties. In addition, defining the purpose helps to clarify the approach that should be taken. The specific approach will vary to some degree depending upon whether the project is a Section 404 permit review, an Advanced Identification (ADID), Special Area Management Plan (SAMP), or some other scenario.

Characterize the project area

Characterizing the project area involves describing the area in terms of climate, surficial geology, geomorphic setting, surface and groundwater hydrology, vegetation, soils, land use, proposed impacts, and any other characteristics and processes that have the potential to influence how wetlands in the project area perform functions. The characterization should be written and accompanied by maps and figures that show project area boundaries, jurisdictional wetlands, the boundaries of the WAA (discussed later in this chapter), proposed impacts, roads, ditches, buildings, streams, soil types, plant communities, threatened or endangered species habitat, and other important features. Some sources of information useful in characterizing a project area are aerial photographs, topographic and NWI maps, and county soil surveys.

Screen for red flags

Red flags are features within or in the vicinity of the project area to which special recognition or protection has been assigned on the basis of objective criteria (Table 9). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the wetlands or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of

wetland functions. An assessment of wetland functions may not be necessary if the project is unlikely to occur as a result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of wetland functions may be unnecessary since the project may be denied or modified strictly on the basis of the impacts to threatened or endangered species or habitat.

Table 9. Red flag features and respective program/agency authority.

Red Flag Features	Authority[1]
Native Lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA or RCRA	I
Areas protected by a Coastal Zone Management Plan	E
Areas providing Critical Habitat for Species of Special Concern	B, C, F
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or floodprone areas	J
Areas with structures/artifacts of historic or archeological significance	G
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	B, D
National wildlife refuges and special management areas	C
Areas identified in the North American Waterfowl Management Plan	C, F
Areas identified as significant under the RAMSAR Treaty	H
Areas supporting rare or unique plant communities	C, H
Areas designated as Sole Source Groundwater Aquifers	I, L
Areas protected by the Safe Drinking Water Act	I, L
City, County, State, and National Parks	D, F, H, L
Areas supporting threatened or endangered species	B, C, F, H, I
Areas with unique geological features	H
Areas protected by the Wild and Scenic Rivers Act	D
Areas protected by the Wilderness Act	D
[1]Program Authority / Agency A = Bureau of Indian Affairs B = National Marine Fisheries Service C = U.S. Fish and Wildlife Service D = National Park Service E = State Coastal Zone Office F = State Departments of Natural Resources, Fish and Game, etc. G = State Historic Preservation Office H = State Natural Heritage Offices I = U.S. Environmental Protection Agency J = Federal Emergency Management Agency K = Natural Resources Conservation Service L = Local Government Agencies	

Define the Wetland Assessment Area (WAA)

The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage, etc.). In many project areas, there will be just one WAA representing a single wetland subclass, as illustrated in Figure 21. However, as the size and heterogeneity of the project area increase, it may be necessary to define and assess multiple WAAs or Partial Wetland Assessment Areas (PWAAs) within the project area.

At least three situations necessitate defining and assessing multiple WAAs or PWAAs within a project area. The first situation exists when widely separated wetland patches of the same regional subclass occur in the project area (Figure 22). The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 23). The third situation exists when a physically contiguous wetland area of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into a significantly different value for one or more of the site-specific variable measures. These differences may be a result of natural variability (e.g., zonation on large river floodplains) or cultural alteration (e.g., logging, surface mining, hydrologic alterations) (Figure 24). Designate each of these areas as a separate PWAA and conduct a separate assessment on each area.
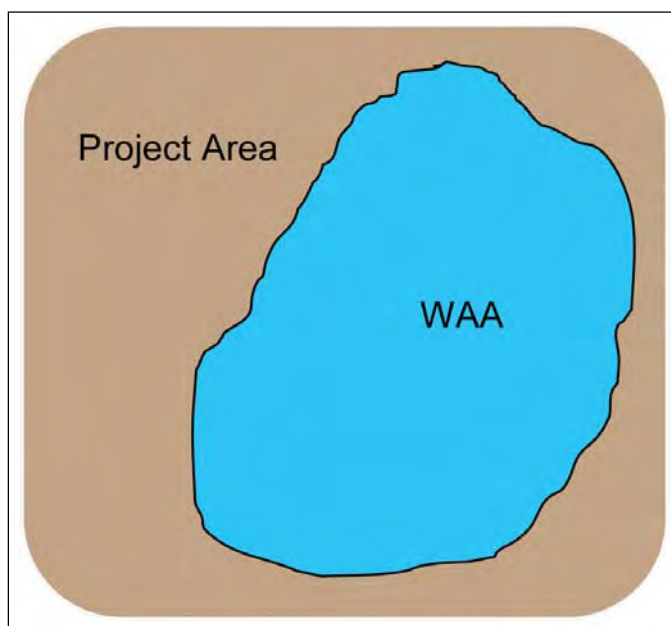
Figure 21. A single WAA within a project.
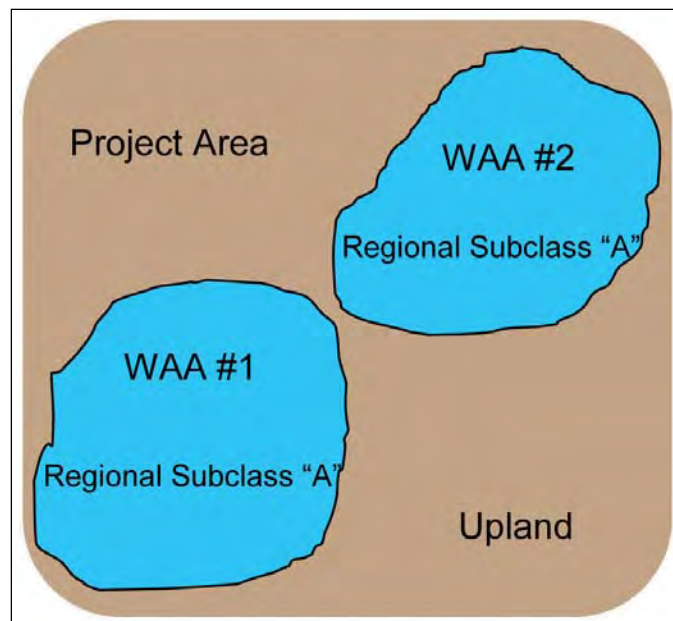
Figure 22. Spatially separated WAAs from the same regional subclass within a project.
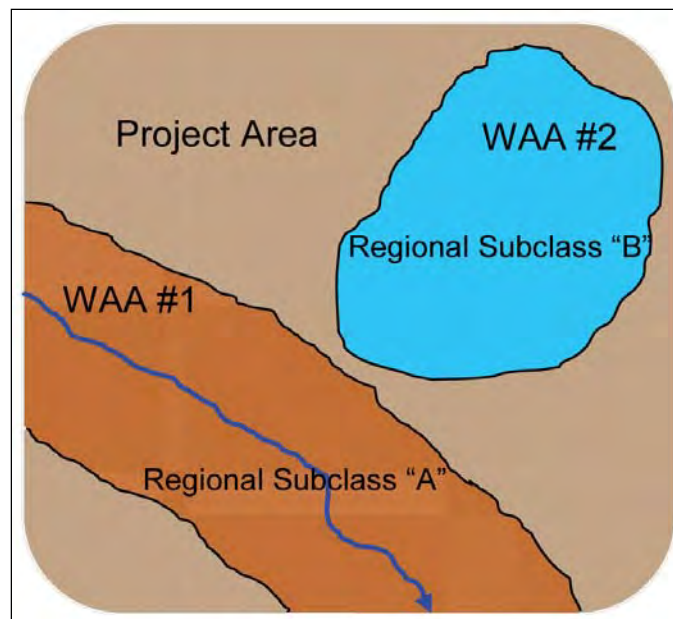
Figure 23. More than one regional subclass within a project area.
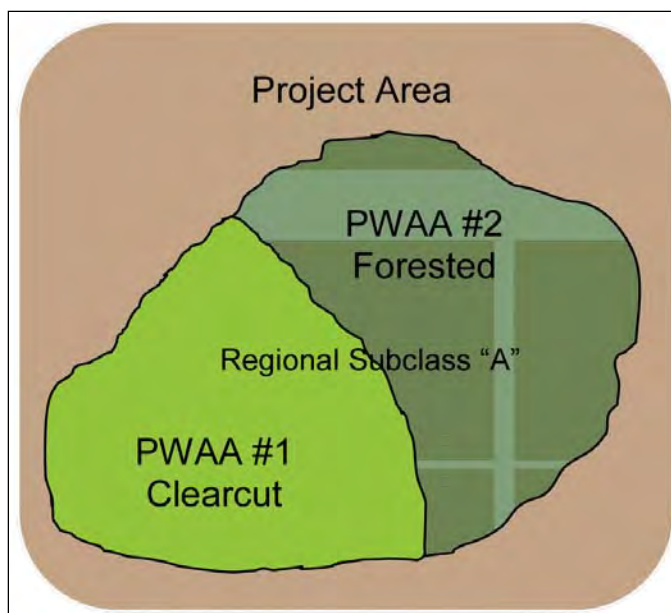
Figure 24. PWAAs defined on the basis of differences in site-specific characteristics.

There are elements of subjectivity and practicality in determining what constitutes a significant difference in portions of the WAA. Field experience with the regional wetland subclass under consideration should provide a sense of the range of variability that typically occurs, and the understanding necessary to make reasonable decisions about defining multiple PWAAs. For example, in Headwater Slope wetlands, recent logging in a portion of a wetland area may be a criterion for designating two PWAAs. The presence of relatively minor differences resulting from natural variability should not be used as a basis for dividing a contiguous wetland into multiple PWAAs. However, zonation caused by different hydrologic regimes or disturbances caused by rare and destructive natural events (e.g., hurricanes) should be used as a basis for defining PWAAs.

Determine the wetland subclass

This guidebook describes Headwater Slope wetlands found in the Coastal Plain of South Carolina. Determining the correct subclass is essential to completing a meaningful HGM assessment. Subclasses are based on hydrogeomorphic characteristics. Headwater Slope wetlands in the reference domain were defined previously as headwater wetlands, including those associated with first-order streams that are supported by precipitation and groundwater inputs from the surrounding uplands and are not dominated by riverine processes. Current aerial photographs,

topographic maps, soils maps, NWI maps, local knowledge, or other available information can be used to help identify Headwater Slope wetlands and distinguish them from riverine (floodplain) systems. In some cases, however, it will not be possible to determine the wetland subclass from remotely sensed data or maps, and on-site investigation will be necessary. Some extremely disturbed sites will be difficult to evaluate even during an on-site examination. In these cases, historical aerial photographs or knowledge of local experts may be helpful in determining the wetland subclass.

Collect the data

The first step in data collection is to identify and delineate the project area and WAA or PWAAs on aerial photographs and topographic maps. Always use the most recent and highest quality images and maps available. It usually will be necessary to verify decisions made from photo interpretation in the field during field reconnaissance.

Variables used in the models to assess wetland functions were defined and discussed in Chapter 4. Information needed to estimate the variables is collected at various spatial scales. The first three variables (V_{CATCH}, V_{UPUSE}, and $V_{CONNECT}$) are landscape-scale variables that describe conditions in the wetland's catchment or watershed. These variables are evaluated using aerial photographs, maps, and field reconnaissance of the area surrounding the WAA. Aerial photography may also be useful in determining $V_{SOILALT}$, although it should be confirmed during a walking reconnaissance of the WAA, since outdated photography might not show the extent of current disturbance, and bedding may be difficult to pick up on an aerial photograph. A walking reconnaissance of the WAA itself is needed to evaluate the variable $V_{HYDROALT}$. Finally, detailed, site-specific data collected within sample plot(s) or subplots at representative locations within the WAA are needed to estimate the remaining variables. The data sheets shown in Figure 25 are organized to facilitate data collection at each spatial scale. Instructions for measuring each variable are given below. The Excel version of the data sheet completes all necessary calculations to determine variable subindices and functional capacity indices and units.

South Carolina Headwater Slope Wetland HGM Field Data Sheet and Calculator

Assessment Team:		UTM Easting:	
Project Name:		UTM Northing:	
Location:		Sampling Date:	
WAA Number: 0	Plot Number: of	Plot Area (0.04 ha is standard): 0.04	

Top Strata in WAA (trees, sapling/shrub, herbs):   Project/Mitigation Site (circle one)   Before/After Project (circle one)

Sample Variables 1-3 using aerial photography, topographic maps, soil survey maps, etc.

1 V_{CATCH}	Percent change in the size of the catchment (If there is no water diversion or augmentation in the catchment, percent change = 0)	
	Size of original Catchment	
	If diversion: Size of current catchment	
	If augmentation: Size of catchment from which water is being diverted.	

2 V_{UPUSE} Weighted Average of Runoff Score for Catchment:

Land Use (Choose From Drop List)	Soil (Choose From Drop List)	Soil Group	Runoff Score	% in Catchment	Running Percent (not >100)

3 $V_{CONNECT}$ Percent of wetland perimeter connected to suitable habitat (buffer must be at least 10 meters wide).

Total length of wetland perimeter (meters)	
Length of wetland perimeter with suitable habitat at least 10m wide (meters)	
Average width of buffer (meters)	

Sample Variables 4-5 during onsite field reconnaissance.

4 $V_{SOILINT}$ Weighted Average of Alterations to Soil Integrity within WAA:

Soil Alteration	Variable Subindex	% in WAA	Running Percent (not >100)

5 $V_{HYDROALT}$ Height of obstruction, depth of ditch, or depth of impounded water. (cm)

Figure 25. Sample field data sheet for South Carolina Headwater Slope wetlands (continued).

Sample Variables 6-13 within one or more representative 0.04-ha (0.1-acre) plot(s) within the WAA (use a separate data sheet for each)

6	V_{CTD}	Average dbh of canopy trees (measure only if total tree cover is at least 20%)

List the dbh measurements of individual canopy trees (at least 10cm) below:

Subplot 1		Subplot 2		Subplot 3		Subplot 4	

7	V_{CTDEN}	Average number of canopy trees per ha (=canopy trees in 0.04 ha plot x 25)

8	V_{SSC}	Average percentage cover of saplings/shrubs (measure only if tree cover is <20%). Must be at least 20%.

Subplot 1 ___ Subplot 2 ___ Subplot 3 ___ Subplot 4 ___

9	V_{GVC}	Average percentage cover of ground-layer vegetation (measure only if tree and sapling/shrub cover are each <20%)

Subplot 1 ___ Subplot 2 ___ Subplot 3 ___ Subplot 4 ___

10	V_{COMP}	Vegetation Composition and Diversity (Check all dominant species in the tallest stratum. Check all exotics and invasives, including non-dominants, in all strata on plot)

Group 1 = 1.0		Group 2 = 0.66	
☐ Acer rubrum	☐ Quercus laurifolia	☐ Carpinus caroliniana	☐ Ilex opaca
☐ Carya cordiformis	☐ Quercus michauxii	☐ Celtis laevigata	☐ Liquidambar styraciflua
☐ Fraxinus caroliniana	☐ Quercus nigra	☐ Cornus foemina	☐ Liriodendron tulipifera
☐ Fraxinus pennsylvanica	☐ Quercus pagoda	☐ Diospyros virginiana	☐
☐ Fraxinus profunda	☐ Quercus phellos	☐	☐
☐ Magnolia grandiflora	☐ Taxodium distichum	☐	☐

Group 1 = 1.0 (continued)		Groups 3 = 0.00	
☐ Magnolia virginiana	☐ Ulmus americana		
☐ Nyssa aquatica	☐	☐ Albizia julibrissin	☐ Lonicera japonica
☐ Nyssa sylvatica	☐	☐ Alternanthera philoxeroides	☐ Lygodium japonicum
☐ Nyssa sylvatica var. biflora	☐	☐ Arundo donax	☐ Microstegium vimineum
☐ Persea borbonia	☐	☐ Cyperus iria	☐ Panicum repens
☐ Pinus glabra		☐ Echinochloa crus-galli	☐ Pueraria montana
☐ Pinus taeda		☐ Imperata cylindrica	☐ Sorghum halepense
		☐ Ligustrum japonicum	☐ Triadica sebifera
		☐ Ligustrum sinense	☐ Verbena brasiliensis
If the site is completely unvegetated, choose a Group 3 box to force V_{COMP} to 0.		☐	☐

0 Species in Group 1	0 Species in Group 2	0 Species in Group 3
Initial Quality Index:	Adjusted Quality Index:	

Figure 25 (continued).

11	$V_{DETRITUS}$	Average percent cover of leaves, sticks, or other organic material	
		Subplot 1 Subplot 2 Subplot 3 Subplot 4	
12	V_{SSOM}	Average Munsell soil color value (must be 2-8)	
		Subplot 1 Subplot 2 Subplot 3 Subplot 4	
13	V_{WD}	Volume per hectare of non-living fallen woody stems (m³/ha).	

	Transect 1	Transect 2
Number of stems with diameters greater than or equal to 0.6 cm (0.25 in) and less than 2.5 cm (1 in) in diameter intersecting a 6-ft length of the 50-foot transect:		
Number of stems with diameters greater than or equal to 2.5 cm (1 in) and less than 7.6 cm (3 in) in diameter intersecting a 6-ft length of the 50-foot transect:		
Enter diameters (cm) of each fallen woody stem 7.6 cm (3 inches) or greater in diameter in each 50-foot transect:		

Summary: Plot Number 0

Notes:

Variable	Value	VSI
V_{CATCH}		
V_{UPUSE}		
$V_{CONNECT}$		
Avg. width		
$V_{SOILINT}$		
$V_{HYDROALT}$		
V_{CTD}		
V_{CTDEN}		
V_{SSC}		
V_{GVC}		
V_{COMP}		
$V_{DETRITUS}$		
V_{SSOM}		
V_{WD}		

Function This Plot ONLY	FCI
Water Storage	
Cycle Organic Carbon	
Maintain a Characteristic Plant Community	
Provide Characteristic Wildlife Habitat	

Figure 25 (concluded).

The data sheets shown in Figure 25 are actually part of a spreadsheet, available for download, that will conduct all the calculations described below, including any weighted averaging, calculating woody debris volume per hectare from diameters, and translating variable values (i.e., woody debris volume per hectare (m³/ha)) into subindex scores based on the curves presented in Chapter 4. This spreadsheet calculator is the easiest way to do the calculations, but the descriptions below and in the supplemental data sheets in the appendices will allow a user to make these calculations by hand, if desired.

Landscape-scale Variables

Change in catchment size (V_{CATCH})

Measure/Units: Percent change in the effective size of the wetland catchment or basin. Use the following procedure to measure V_{CATCH}:

1. If there are no ditches, drains, or water diversions in the wetland's catch-ment, and no augmentation of hydrology through interbasin transfers of water, then the percent change in catchment size is 0 (subindex for V_{CATCH} = 1.0) and the following steps may be skipped. Otherwise, use aerial photographs, topographic maps, or field reconnaissance to delineate the catchment or watershed of the Headwater Slope wetland.
2. Determine the total area of the catchment under natural conditions (i.e., overlooking any diversions or drains that may be present).
3. Determine the existing catchment area by subtracting those portions of the natural catchment from which surface or subsurface water is being diverted away from the wetland. In the case of water transfer into the wetland's catchment from an adjacent basin, determine the area of the basin (or portion of the basin) from which water is being transferred.
4. Use Equation 1 or 2 in Chapter 4, whichever is appropriate, to calculate the percent change in effective catchment size.
5. Use Figure 5 to determine the subindex score for V_{CATCH}. If the effective size of the catchment is unchanged (i.e., no water diversions), the subindex score is 1.0.

Upland land use (V_{UPUSE})

Measure/Units: Weighted average runoff score for the catchment that provides water to the Headwater Slope wetland. Use the following procedure to measure V_{UPUSE}:

1. Use topographic maps or other sources to delineate the existing catchment or watershed of the Headwater Slope Wetland. Do not include areas from which water is being diverted away from the wetland; include any adjacent catchment area from which water is being imported into the wetland's catchment (see V_{CATCH} above).
2. Use recent aerial photographs or field reconnaissance to determine the land-use categories (Table 5) present in the catchment.
3. Use a local soil survey or on-site soil sampling to determine the soil series that occur in the catchment. Based on information in the soil survey, determine the hydrologic group(s) (i.e., A, B, C, or D) for the soils present in the catchment.
4. Using GIS techniques, aerial photos, or field reconnaissance, determine the percentage of the catchment represented by each combination of land-use category and soil hydrologic group shown in Table 5.
5. Determine the runoff score for each combination of land-use category and soil hydrologic group present in the catchment (Table 5).
6. Determine a weighted (by area) average runoff score for the catchment. An example can be found in Appendix B.
7. Use Figure 6 to determine the subindex score for V_{UPUSE}.

Soil integrity (V$_{SOILINT}$)

Measure/Units: Weighted average index for the Headwater Slope WAA. Use the following procedure to measure $V_{SOILINT}$:

1. Use topographic maps or other sources to delineate Headwater Slope WAA.
2. Use recent aerial photographs and field reconnaissance to determine the soil alteration categories (Table 6) present in the WAA.
3. Using GIS techniques, aerial photos, or field reconnaissance, determine the percentage of the catchment represented by each soil alteration category in Table 6.
4. Determine the subindex for each soil alteration category present in the WAA (Table 6).
5. Determine a weighted (by area) average variable subindex for the WAA.
6. Use this weighted average as the subindex score for $V_{SOILINT}$.

Habitat connections ($V_{CONNECT}$)

Measure/Units: Percentage of the wetland's perimeter and width that is connected to suitable habitat. Use the following procedure to measure $V_{CONNECT}$:

1. Determine the total length and average width of the wetland perimeter using field reconnaissance, topographic maps, aerial photographs, or GIS techniques.
2. Determine the length of the wetland perimeter that has a suitable habitat buffer at least 10 m (32.8 ft) in width (Figure 7). See Chapter 4 for examples of suitable habitat types.
3. Divide the length of wetland perimeter having suitable buffer width by the total length of the wetland perimeter.
4. Convert to a percentage by multiplying by 100.
5. Use the top series in Figure 8 to determine the connection index for $V_{CONNECT}$.
6. Multiply the connection index by 0.33 if the average perimeter width is $\geq$ 10 m and <30 m (32.8-98.4 ft) wide, 0.66 if the average perimeter width is > 30 m and < 150 m (98.4-492 ft), or 1.0 if the average perimeter width is $\geq$ 150 m (492 ft) to determine the subindex score for $V_{CONNECT}$. Alternatively, these subindex scores can be read directly off the middle and lower series in Figure 8.

Wetland-scale variable

Hydrologic alterations ($V_{HYDROALT}$)

Measure/Units: This variable is quantified by the height of any dam, berm, or water-control structure or depth of any ditch located within the wetland, or by the maximum depth of water impounded in the wetland. Use the following procedure to measure $V_{HYDROALT}$:

1. If wetland hydrology is unaltered and there are no obstructions to natural water storage or flow, and there are no ditches or excessive ponding within the wetland, then the height is 0, the subindex score for $V_{HYDROALT}$ is 1.0, and the following steps may be skipped.
2. If wetland hydrology has been altered, identify any permanent obstructions to surface water flow such as dams or road crossings, any ditches that increase drainage, or standing water that covers more than 70 percent of the wetland surface. Natural microtopography or even wheel

and tire ruts do not alter the natural hydrology of a Headwater Slope wetland appreciably.

3. Measure the height of the obstruction, depth of the ditch, or depth of ponded water in centimeters from the natural ground surface.

4. Use Figure 10 to determine the subindex score for $V_{HYDROALT}$.

Plot-scale variables

Data on vegetation and soil conditions in Headwater Slope wetlands are collected within one or more 0.04-ha (0.1-acre) sample plot(s), each divided into four equal subplots (Figure 26). Plots are needed to determine the density of trees, if present. They also make the estimation of percent cover of saplings/shrubs, ground-layer vegetation, and organic litter easier and more accurate. Some vegetation and soil variables are sampled on subplots as a way to determine average conditions when there is variability across the larger plot.
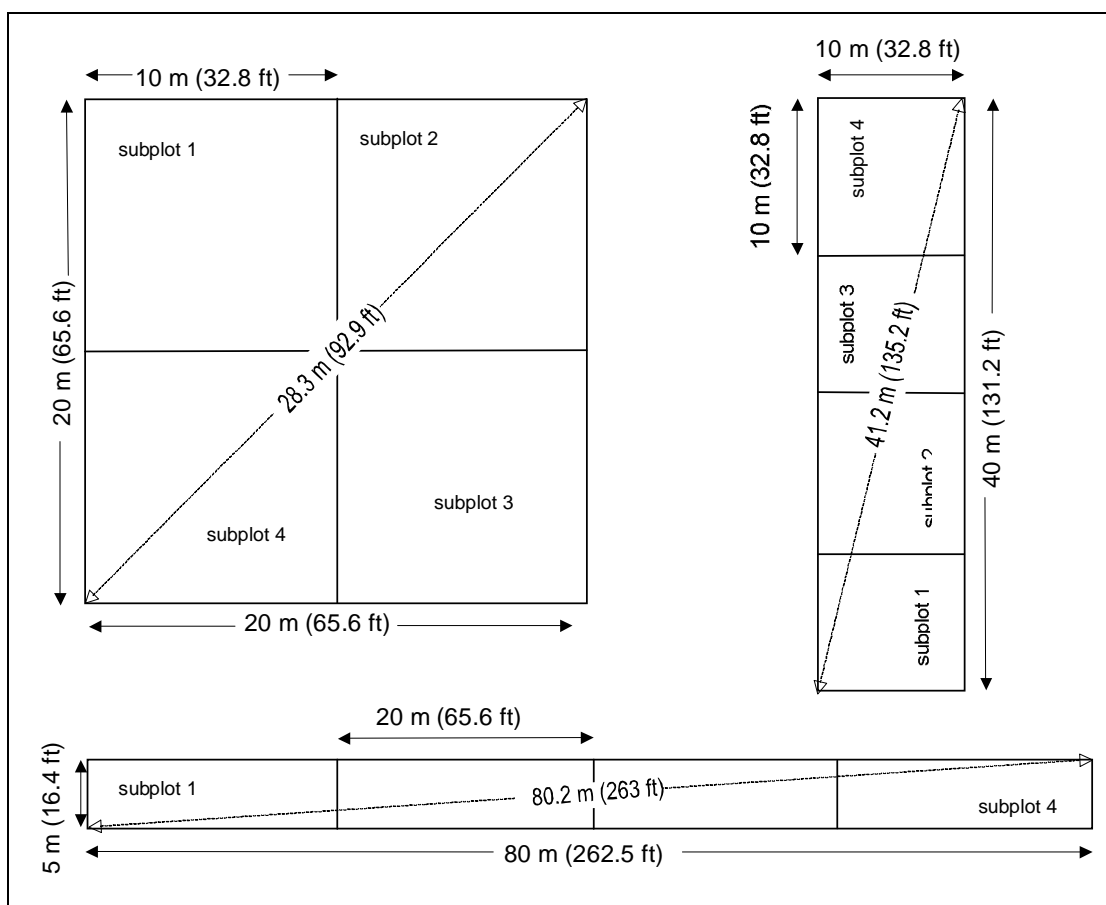
Figure 26. Examples of plot and subplot shapes that equal 0.04 ha (0.1 acre).

The following equipment is needed to establish the sample plot(s) and measure the plot-based variables:

- A 50-m measuring tape, stakes, corner prism (optional), and flagging
- Plant identification references or keys
- Soil probe or sharpshooter shovel

While a 0.04-ha (0.1-acre) square plot is fairly easy to lay out, the size and shape of the wetland may require a rectangular plot or some other shape. Figure 26 shows examples of rectangular plots measuring 10×40 m and 5×80 m, which also cover 0.04 ha but may fit better within a narrow, linear wetland. Furthermore, the subplots do not need to be contiguous if separating them would fit better within a meandering drainage. Any combination of plot sizes and shapes that equals 0.04 ha is recommended. If the wetland is smaller than 0.04 ha, the entire wetland may be sampled. In cases where odd-sized plots or the entire wetland are sampled, the area sampled will need to be determined to calculate the density of canopy trees (V_{CTDEN}) in stems/ha.

Canopy tree diameter (V_{CTD})

Measure/Units: Average diameter at breast height (dbh in cm) of all *canopy* trees within a 0.04-ha (0.1-acre) plot. Use the following procedure to measure V_{CTD}:

1. This variable is measured only if the total cover of trees ≥10 cm (4 in.) dbh in the wetland is ≥20 percent. If tree cover is <20 percent, the following steps may be skipped.
2. Measure the dbh (cm) of all *canopy* trees within a 0.04-ha (0.1-acre) plot or, alternatively, within each of four 0.01-ha (0.025-acre) subplots. See Chapter 4 and Figure 11, or the glossary (Appendix A), for the definition of a canopy tree.
3. Calculate the mean canopy tree diameter by summing dbh measurements across subplots and dividing by the total number of trees measured.
4. If multiple 0.04-ha plots are sampled, average the results from all plots.
5. Report the mean canopy tree diameter in centimeters.
6. Use Figure 12 to determine the subindex score for V_{CTD}.

Canopy tree density (V_CTDEN)

Measure/Units: Number of canopy trees (or stems) per hectare. Use the following procedure to measure V_{CTDEN}:

1. Measure this variable only if the total cover of trees $\geq$10 cm (4 in.) dbh in the wetland is $\geq$20 percent. If tree cover is <20 percent, the following steps may be skipped.
2. Use the data gathered for V_{CTD} to determine the number of canopy trees in a 0.04-ha (0.1-acre) plot.
3. Convert this result to a per hectare basis by multiplying by 25 (there are 25 0.04-ha plots in each hectare).
4. If multiple 0.04-ha plots are sampled, average the results from all plots.
5. Report canopy tree density as the number of trees per hectare.
6. Use Figure 13 to determine the subindex score for V_{CTDEN}.

Sapling/shrub cover (V_SSC)

Measure/Units: Average percent cover of saplings and shrubs. Use the following procedure to measure V_{SSC}:

1. Measure this variable only if total tree cover is <20 percent and cover of sapling/shrubs is $\geq$20 percent. See Chapter 4 or the glossary (Appendix A) for the definition of saplings and shrubs.
2. Visually estimate the percent cover of saplings/shrubs within a 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. If necessary, average the results across subplots.
3. Average the percent cover estimates if more than one 0.04-ha plot is sampled.
4. Report the average sapling/shrub cover as a percent.
5. Use Figure 14 to determine the subindex score for V_{SSC}.

Ground vegetation cover (V_GVC)

Measure/Units: Average percent cover of ground-layer vegetation. Use the following procedure to measure V_{GVC}:

1. Measure this variable only if tree and sapling/shrub cover are each <20 percent. See Chapter 4 or the glossary (Appendix A) for the definition of ground-layer vegetation.

2. Visually estimate the percent cover of ground-layer vegetation within a 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. If necessary, average the results across subplots.
3. Average the percent cover estimates if more than one 0.04-ha plot is sampled.
4. Report ground vegetation cover as a percent.
5. Use Figure 15 to determine the subindex score for V_{GVC}.

Vegetation composition and diversity (V_{COMP})

Measure/Units: An index based on the species composition and number of dominant species in the uppermost stratum of the wetland's vegetation. Use the following procedure to measure V_{COMP}:

1. If total tree cover is $\geq$20 percent, then V_{COMP} is determined for the tree stratum. If tree cover is <20 percent and sapling/shrub cover is $\geq$20 percent, then V_{COMP} is determined for the sapling/shrub stratum. If tree cover and sapling/shrub cover are both <20 percent, then V_{COMP} is determined for the ground layer, even if the ground layer has <20 percent vegetation cover.
2. Use the "50/20 rule" (see Figure 16) to identify the dominant species in the appropriate vegetation stratum. For sites containing a tree stratum, be sure to consider all trees $\geq$10 cm (4 in.) dbh and not just "canopy" trees.
3. On the data form, place a check beside each dominant species that appears in either Group 1 or 2 (Table 7). If a dominant species is not listed but is a species native to the reference domain, it can be added to Group 2 using the blanks provided. For exotic and invasive species in the reference domain (Group 3), check all species encountered on the plot without regard to dominance or stratum. Other exotic and invasive species can be added using the blanks provided and should be treated as Group 3 species. The data form does not list herbaceous plants due to the potentially very long list. Assign all native, non-invasive herb species to Group 1. Invasive and exotic herb species that occur in wetlands in the reference domain should be listed in Group 3.
4. Using the checked dominants in Groups 1 and 2, and the checked exotic or invasive species in Group 3, calculate an initial quality index (Q) using the following formula:

$$Q = [(1.0 \times \textit{number of checked dominants in Group 1}) + (0.66 \times \textit{number of checked dominants in Group 2}) + (0.0 \times \textit{number of}$$

checked species in Group 3)] / *total number of checked species in all groups*

5. Calculate an adjusted quality index (R) that takes species richness into consideration. Multiply Q by one of the following constants:

   a. If four or more species from Groups 1 or 2 occur as dominants, multiply by 1.0 (i.e., R = Q × 1.0).
   b. If three species from Groups 1 or 2 occur as dominants, multiply by 0.75 (i.e., R = Q × 0.75).
   c. If two species from Groups 1 or 2 occur as dominants, multiply by 0.50 (i.e., R = Q × 0.50).
   d. If one species from Groups 1 or 2 occurs as a dominant, multiply by 0.25 (i.e., R = Q × 0.25).
   e. If no species from Groups 1 or 2 occur as dominants, multiply by 0.0 (i.e., R = Q × 0.0).

   (In a small assessment area (e.g., <0.25 ha), it is possible that fewer than four species may be dominant, even in a high-quality community. In such cases, at the discretion of the user, Q can be multiplied by 1.0, even if as few as two species are dominant.)

6. Calculate the square root of R. This is the subindex for vegetation composition and diversity (V_{COMP}).

Soil detritus ($V_{DETRITUS}$)

Measure/Units: Average percentage of the ground surface covered by leaves, sticks, or other organic material. Use the following procedure to measure $V_{DETRITUS}$:

1. Visually estimate the percent cover of leaves, sticks, or other organic material within each 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. See Chapter 4 or the Glossary (Appendix A) for the definition of detritus. If necessary, average the results across subplots.
2. Average the percent cover estimates if more than one 0.04-ha plot is sampled.
3. Report the average cover of detritus as a percent.
4. Use Figure 18 to determine the subindex score for $V_{DETRITUS}$.

Surface soil organic matter (V_{SSOM})

Measure/Units: Average Munsell® soil color value. Use the following procedure to measure V_{SSOM}:

1. At four representative locations within each 0.04-ha (0.1-acre) plot, or at one representative location in each 0.01-ha (0.025-acre) subplot, use a soil probe or shovel and excavate the soil to a depth of about 15 cm (6 in.). Determine the color value of the surface soil layer, below the detrital layer, to the nearest color chip using a Munsell soil color chart.
2. Average all of the Munsell soil color values across sampling points.
3. Report surface soil organic matter as a number between 2 and 8.
4. Use Table 8 to determine the subindex score for V_{SSOM}.

Woody debris biomass (V_{WD})

Woody debris is an important habitat and nutrient cycling component of forests. Volume of woody debris and log biomass per hectare is the metric used to quantify these variables. Measure them with the procedure outlined below (Brown 1974; Brown et al. 1982): (Note: all stem diameter criteria and measurements for all size classes refer to diameter at the point of intersection with the transect line. Leaning dead stems that intersect the sampling plane are sampled. Dead trees and shrubs still supported by their roots are not sampled. Rooted stumps are not sampled, but uprooted stumps are sampled. Down stems that are decomposed to the point where they no longer maintain their shape but spread out on the ground are not sampled).

1. Lay out two 50-ft (15.24-m) east-west transects, originating at the 0.04-ha plot center point.
2. Count the number of nonliving stems in Size Class 1 (small) (greater than or equal to 0.6 and less than 2.5 cm or greater than or equal to 0.25 and less than 1 in) that intersect a vertical plane above a 6-ft segment of each 50-ft transect. This can be any 6-ft segment, as long as it is consistently placed. Record the number of Size Class 1 stems from each transect in the spaces provided on the V_{WD} (Size Class 1) line on the data sheet.
3. Count the number of nonliving stems in Size Class 2 (medium) (greater than or equal to 2.5 cm and less than 7.6 cm or greater than or equal to 1 in. and less than 3 in.) that intersect the plane above a 12-ft segment of each 50-ft transect. This can be any 12-ft segment, as long as it is consistently

placed. Record the number of Size Class 2 stems from each transect in the spaces provided on the V_{WD} (Size Class 2) line on the data sheet.

4. Measure and record the diameter of nonliving stems in Size Class 3 (large) (greater than or equal to 7.6 cm or greater than or equal to 3 in) that intersect the plane above the entire length of the 50-ft transect. Record the diameter of individual stems (in centimeters) in Size Class 3 from each transect in the spaces provided on the V_{WD} (Size Class 3) section of the data sheet.

5. If not using the calculator spreadsheet, use the worksheet in Appendix B to hand calculate V_{WD} (m³/ha) from the tally and diameter measurements.

6. Use Figure 19 to determine the subindex score for V_{WD}.

Analyze the data

The first step in analyzing the field data is to transform the field measure of each assessment variable into a variable subindex on a scale of 0 to 1.0. This can be done using the graphs and tables in Chapter 4, or will be done automatically if using the spreadsheet calculator. The second step is to insert the variable subindices into the equations for each assessment model and calculate the FCIs using the relationships defined in the models. Again, this can be done manually or automatically using a spreadsheet. Finally, multiply the FCI for each function by the total size of the WAA to calculate the number of Functional Capacity Units (FCUs) for each function (Smith et al. 1995).

Apply assessment results

Once the assessment and analysis phases are complete, the results can be used to compare the level(s) of function in the same WAA at different points in time or in different WAAs at the same point in time. The information can be used to address the specific objectives identified at the beginning of the study, such as (a) determining project impacts, (b) comparing project alternatives, (c) determining mitigation requirements, and (d) evaluating mitigation success.

To evaluate project-related impacts, at least two assessments will generally be needed. The first assesses the number of FCUs provided by the site in its pre-project condition. The second assesses the number of FCUs provided by the site in a post-project state, based on proposed project plans and the associated changes to each of the model variables. The difference between pre-project and post-project conditions, expressed in

numbers of FCUs, represents the potential loss of functional capacity due to project impacts. Similarly, in a mitigation scenario, the difference between the current condition and future condition of a site, with mitigation actions implemented and successfully completed, represents the potential gain in functional capacity as a result of restoration activities. However, since the mitigation project is unlikely to become fully functional immediately upon completion, a time lag must be incorporated in the analysis to account for the time necessary for the mitigation site to achieve full functional development.

For more information on the calculation of FCUs and their use in project assessments, see Smith et al. (1995). Spreadsheets useful in evaluating project impacts and estimate mitigation requirements are available on the web (http://el.erdc.usace.army.mil/wetlands/datanal.html).

References

Ainslie, W. B. 2002. Forested wetlands. In *Southern forest resource assessment*, ed. D. N. Wear, J. G. Greis, 635. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Ainslie, W. B., Smith, R. D., Pruitt, B. A., Roberts, T. H., Sparks, E. J., West, L., Godshalk, G. L., and Miller, M. V. 1999. *A regional guidebook for assessing the functions of low gradient, riverine wetlands in western Kentucky*. Technical Report WRP-DE-17. Vicksburg, MS: U. S. Army Engineer Waterways Experiment Station.

Allen, A. W. 1987. *Habitat suitability index models: Gray squirrel, revised.* Biological Report 10.135. Washington, DC: U. S. Fish and Wildlife Service.

Anderson, S. H., and H. H. Shugart, Jr. 1974. Habitat selection of breeding birds in an east Tennessee deciduous forest. *Ecology* 55: 828-837.

Andreas, B. K., and R. W. Lichvar. 1995. *Floristic index for establishing assessment standards: A case study for northern Ohio.* Wetlands Research Program Technical Report WRP-DE-8. Vicksburg, MS: U. S. Army Corps of Engineers Waterways Experiment Station.

Askins, R. A., M. J. Philbrick, and D. S. Sugeno. 1987. Relationship between the regional abundance of forest and the composition of forest bird communities. *Biological Conservation* 39: 129-52.

Aust, W. M. 1994. Timber harvesting considerations for site protection in southeastern forested wetlands. *Proceedings, Workshop on Water Management in Forested Wetlands*, Technical Publication R8-TP-20, USDA Forest Service, 5-12.

Bailey, M. A., J. N. Holmes, and K. A. Buhlmann. 2004. *Habitat management guidelines for amphibians and reptiles of the southeastern United States*. Partners in Amphibian and Reptile Conservation Technical Publication HMG-2.

Beaulac, N. M., and K. H. Reckhow. 1982. An examination of land use nutrient export relationships. *Water Resources Bulletin* 18(6): 101324.

Bolen, E. G., and W. L. Robinson. 2003. *Wildlife ecology and management, 5th ed.* Upper Saddle River, NJ: Prentice Hall.

Bolen, E. G., L. H. Smith, and H. L. Schramm. 1989. Playa lakes - prairie wetlands of the southern high plains. *Bioscience* 39: 615-23.

Bonham, C. D. 1989. *Measurements for terrestrial vegetation.* New York: John Wiley and Sons.

Bormann, F. H., and G. E. Likens. 1970. The nutrient cycles of an ecosystem. *Scientific American* 223: 92-101.

Boyd, L. 2001. *Buffer zones and beyond: Wildlife use of wetland buffer zones and their protection under the Massachusetts Wetland Protection Act.* Amherst, MA: Wetland Conservation Professional Program, Department of Natural Resources Conservation, University of Massachusetts.

Boynton, A. C. 1994. Wildlife use of southern Appalachian wetlands in North Carolina. *Proceedings of the Southern Appalachian Man and the Biosphere Conference on "Wetland Ecology, Management, and Conservation,"* Knoxville, TN.

Braun, E. L. 1950. *Deciduous forests of eastern North America.* London: The Free Press, Collier Macmillan Press.

Brinson, M. M. 1993. *A hydrogeomorphic classification for wetlands.* Technical Report WRP-DE-4. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

_____. 1995a. Assessing wetland functions using HGM. *National Wetlands Newsletter,* January/February. Washington, D.C.: Environmental Law Institute.

_____. 1995b. The hydrogeomorphic approach explained. *National Wetlands Newsletter,* November/December. Washington, D.C.: Environmental Law Institute.

Brinson, M. M., F. R. Hauer, L. C. Lee, W. L. Nutter, R. D. Rheinhardt, R. D. Smith, and D. Whigham. 1995. *A guidebook for application of hydrogeomorphic assessments to riverine wetlands.* Technical Report WRP-DE-11. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Brinson, M. M., R. D. Smith, D. F. Whigham, L. C. Lee, R. D. Rheinhardt, and W. L. Nutter. 1998. Progress in development of the hydrogeomorphic approach for assessing the functioning of wetlands. In *Proceedings, INTECOL International Wetland Conference, Perth, Australia.*

Brinson, M. M., W. L. Nutter, R. Rheinhardt, and B. A. Pruitt. 1996. *Background and recommendations for establishing reference wetlands in the Piedmont of the Carolinas and Georgia.* EPA/600/R-96/057. Corvallis, OR: U.S. Environmental Protection Agency National Health and Environmental Effects Laboratory, Western Division.

Brittingham, M. C., and S. A. Temple. 1983. Have cowbirds caused forest songbirds to decline? *BioScience* 33: 31-35.

Brower, J. H., and J. H. Zar. 1984. *Field and lab methods for general ecology.* Dubuque, IA: William C. Brown.

Brown, J. K. 1974. *Handbook for inventory downed woody material.* General Technical Report INT-16, USDA Forest Service.

Brown, J. K., R. D. Overheu, and C. M. Hohnston. 1982. *Handbook for inventorying fuels and biomass in the interior west.* General Technical Report INT-129. Ogden, UT: USDA Forest Service Intermountain Forest and Range Experiment Station.

Burns, R. M., and B. H. Honkala. 1990. *Silvics of North America, Volume 2, Hardwoods.* Agriculture Handbook 654. Washington, D.C.: U. S. Department of Agriculture, Forest Service.

Burton, T. M., and G. E. Likens. 1975. Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire. *Copeia* 1975: 541-546.

Carlisle, V. W. 2000. *Hydric soils of Florida handbook*, 3d ed. 95-101. Gainesville, FL: Florida Association of Environmental Soil Scientists.

Carpenter, S. R. 1988. *Complex interactions in lake communities*. New York: Springer Verlag.

Cederstrom, D. J., E. H. Boswell, and G. R. Tarver. 1979. *Summary appraisals of the nation's ground-water resources - South Atlantic-Gulf region*. Professional Paper 813-O. Washington, D.C.: U.S. Geological Survey.

Clewell, A.F. 1971. *Natural setting and vegetation of the Florida panhandle*. Contract No. DACW01-77-C-0104. Mobile, AL: U. S. Army Corps of Engineers.

Cody, M. L. 1985. *Habitat selection in birds*. Orlando, FL: Academic Press, Inc.

Coffey, P. L. 1998. Evaluation of early successional bottomland hardwood forests. M. S. thesis, Tennessee Technological University, Cookeville, TN.

Conant, R., and J. T. Collins. 1991. *A field guide to reptiles and amphibians: Eastern and central North America*. Boston, MA: Houghton Mifflin Company.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. *Classification of wetlands and deepwater habitats of the United States*. FWS/OBS-79/31. Washington, D.C.: U.S. Fish and Wildlife Service, Office of Biological Services.

Croonquist, M. J., and R. P. Brooks. 1991. Use of avian and mammalian guilds as indicators of cumulative impacts in riparian wetland areas. *Environmental Management* 15(5): 701-714.

Crow, J. H., and K. B. MacDonald. 1978. Wetland values: Secondary productivity. In *Wetland functions and values: The state of our understanding,* ed. P. E. Greeson, J. R. Clark, and J. E. Clark. Minneapolis, MN: American Water Resources Association.

Crowley, S. C. W., P. Cavanaugh, and C. Griffin. 1996. *WETHINGS, Habitat Assessment Procedures for Wetland Dependant Birds in New England*. Amherst, MA: Department of Forestry and Wildlife Management, Univ. of Massachusetts.

Dahl, T.E. 1999. *South Carolina's wetlands — status and trends 1982 – 1989*. Washington, D.C.: U.S. Department of the Interior, Fish and Wildlife Service.

Dahl, T. E., and C. E. Johnson. 1991. *Status and trends of wetlands in the coterminous United States, mid-1970s to mid-1980s*. Washington, D.C.: U.S. Fish and Wildlife Service.

Daniels, R. B., and J. W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian filters. *Soil Science Society of America Journal* 60: 246-251.

DeGraaf, R. M., M. Yamasaki, and W. B. Leak. 1992. Management of New England northern hardwoods, spruce-fir, and eastern white pine for neotropical migratory birds. In *Status and management of neotropical migratory birds*, Estes Park, CO, September 21-25, 1992, ed. D. M. Finch, and P. W. Stangel. General Technical Report RM-229. Fort Collins, CO: U.S. Forest Service.

Dickinson, C. H., and G. Pugh. 1974. *Biology of plant litter decomposition, Vol. 1.* London, England: Academic Press.

Dodd, C. K., Jr. 2003. *Monitoring amphibians in Great Smoky Mountains National Park.* Circular No. 1258. Washington, D.C.: U.S. Geological Survey.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. San Francisco, CA: W. H. Freeman and Company.

Duellman, W. E., and L. Trueb, L. 1986. *Biology of amphibians.* New York: McGraw-Hill.

Drees, L. R., A. D. Karathanasis, L. P. Wilding, and R. L. Blevins. 1994. Micromorphological characteristics of long-term no-till and conventionally tilled soils. *Soil Sci. Soc. Am Journal* 58:508-17

Ellerbe, C. M. 1974. *South Carolina soils and their interpretations for selected uses.* Columbia, SC: S.C. Land Resources Conservation Commission.

Environmental Laboratory. 1987. *Corps of Engineers wetlands delineation manual.* Technical Report Y-87-1. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Ewel, K. C. 1984. Effects of fire and wastewater on understory vegetation in cypress domes. In *Cypress swamps,* ed. K. C. Ewel and H. T. Odum, Chapter 12. Gainesville, FL: University of Florida Press.

Eyre, F. H. 1980. *Forest cover types of the United States and Canada.* Washington, DC: Society of American Foresters.

Federal Register. 1997. *The National Action Plan to implement the Hydrogeomorphic Approach to assessing wetland functions.* 62(119), June 20, 1997, 33607-33620.

Federico, A. D. 1977. *Investigations of the relationship between land use, rainfall, and runoff quality in the Taylor Creek watershed.* Technical Publication 77-3. West Palm Beach, FL: South Florida Water Management District.

Fenneman, N. M. 1938. *Physiography of Eastern United States.* New York: McGraw-Hill.

Ferren, W. R., Jr., P. L. Fiedler, and R. A. Leidy. 1996a. Wetlands of California. Part I. History of wetland habitat. *Madrono* 43: 105-24.

Ferren, W. R., Jr., P. L. Fiedler, R. A. Leidy, K. D. Lafferty, and L. A. K. Mertes. 1996b. Wetlands of California. Part II. Classification and description of wetlands of the central California and southern California coast and coastal watershed. *Madrono* 43: 125-82.

Ferren, W. R., Jr., P. L. Fiedler, R. A. Leidy, K. D. Lafferty, and L. A. K. Mertes. 1996c. Wetlands of California. Part III. Key to the catalogue of wetlands of the central California and southern California coast and coastal watershed. *Madrono* 43: 183-233.

Ford, R. P. 1990. Habitat relationships of breeding birds and winter birds in forested wetlands of west Tennessee. M. S. thesis, University of Tennessee, Knoxville.

Fredrickson, L. H. 1978. Lowland hardwood wetlands : Current status and habitat values for wildlife. In *Wetland functions and values: The state of our understanding,* ed. P. E. Greeson, J. R. Clark, and J. E. Clark. Minneapolis MN: American Water Resources Association.

Gemborys, S. R., and E. J. Hodgkins. 1971. Forests of small stream bottoms in the Coastal Plain of southwestern Alabama. *Ecology* 52: 70-84.

Gibbons, J. W., and R. D. Semlitsch. 1981. Terrestrial drift fences and pitfall traps: An effective technique for quantitative sampling of animal populations. *Brimleyana* 7: 1-16.

Golet, F. C., and J. S. Larson. 1974. *Classification of freshwater wetlands in the glaciated Northeast.* Resources Publication 116. Washington, DC: U.S. Fish and Wildlife Service.

Griffith, G. E., J. M. Omernik, J. A. Comstock, J. B. Glover, and V. B. Shelburne. 2002. *Ecoregions of South Carolina, U.S. Environmental Protection Agency, Corvallis, OR* (map scale 1:1,500,000).

Grubb, H. F., and P. D. Ryder. 1972. *Effects of coal mining on the water resources of the Tradewater River Basin, Kentucky.* Geological Survey Water-Supply Paper 1940. Washington, DC: U.S. Government Printing Office.

Hamel, P. B. 1992. *Land manager's guide to the birds of the southeast.* Chapel Hill, NC: The Nature Conservancy, Southeastern Region.

Harmon, M. E., J. F. Franklin, and F. J. Swanson. 1986. Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research* 15: 133-302.

Harms, W. R. 1998. Minor alluvial floodplains. In *Southern Forested Wetlands: Ecology and Management,* ed. M.G. Messina and W.H. Conner. Boca Raton, FL: Lewis Publishers.

Harris, L. D., and J. G. Gosselink. 1990. Cumulative impacts of bottomland hardwood forest conversion on hydrology, water quality, and terrestrial wildlife. In *Ecological processes and cumulative impacts illustrated by bottomland hardwood wetland ecosystems,* ed. J. G. Gosselink, L. C. Lee, and T. A. Muir 259-322. Chelsea, MI: Lewis Publishers.

Hauer, F. R., and R. D. Smith. 1998. The hydrogeomorphic approach to functional assessment of riparian wetlands: Evaluating impacts and mitigation on river floodplains in the U.S.A. *Freshwater Biology* 40: 51730.

Hayes, A. J. 1979. The microbiology of plant litter decomposition. *Scientific Progress* 66: 25-42.

Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster. 1994. *Measuring and monitoring biological diversity: Standard methods for amphibians.* Washington, DC: Smithsonian Institution Press.

Horton, J. W., and V. A. Zullo. 1991. *The Geology of the Carolinas. Carolina Geological Society 50th anniversary volume*, ed. J. Horton, Jr. and V. A. Zullo. Knoxville, TN: The University of Tennessee Press.

Hubbard, D. E. 1988. *Glaciated prairie wetland functions and values: A synthesis of the literature*. Biological Report 88(43). Washington, DC: U.S. Fish and Wildlife Service.

Hunter, M. L. 1990. *Wildlife, forests, and forestry: Principles of managing forests for biological diversity*. Englewood Cliffs, NJ: Prentice Hall.

Hupp, C.R. 2000. Hydrology, geomorphology and vegetation of Coastal Plain rivers in the south-eastern USA. *Hydrologic Processes* 14: 2991-3010.

Hupp, C. R., M. D. Woodside, T. M. Yanosky. 1993. Sediment and trace element trapping in a forested wetland, Chichahominy River, VA. *Wetlands* 13: 95-104.

Johnson, T. R. 1987. The amphibians and reptiles of Missouri. Jefferson City, MO: Missouri Department of Conservation.

Kantrud, J. A., G. L. Krapu, and G. A. Swanson. 1989. *Prairie basin wetlands of the Dakotas: A community profile*. Biological Report 85. Washington, DC: U.S. Fish and Wildlife Service.

Kays, R. W., and D. E. Wilson. 2002. *Mammals of North America*. Princeton, NJ: Princeton University Press.

Keller, C. M. E., C. S. Robbins, and J. S. Hatfield. 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. *Wetlands* 13: 137-44.

Kent, M., and P. Coker, P. 1995. *Vegetation description and analysis, a practical approach.* New York: John Wiley and Sons.

Kilgo, J. C., R. A. Sargent, K. V. Miller, and B. R. Chapman. 1997. Landscape influences on breeding bird communities in hardwood fragments in South Carolina. *Wildlife Society Bulletin* 25: 878-85.

Kurz, H., and K. A. Wagner. 1953. Factors in cypress dome development. *Ecology* 34: 157-64.

Laan, R., and B. Verboon. 1990. Effects of pool size and isolation on amphibian communities. *Biological Conservation* 54: 251-262.

Laderman, A. D. 1989. *The ecology of Atlantic white cedar wetlands: A community profile*. U.S. Fish and Wildlife Service Biological Report 85(7.21). 114 pp.

Leibowitz, S. G., and J. B. Hyman. 1997. *Use of scale invariance in assessing the quality of judgment indicators*. Corvallis, OR: U.S. Environmental Protection Agency Laboratory.

Ludwig, J. A., and J. F. Reynolds. 1988. *Statistical ecology: A primer on methods and computing.* New York: John Wiley and Sons.

MacArthur, R. H., and J. W. MacArthur. 1961. On bird species diversity. *Ecology* 42: 594-98.

Mausbach, M. J., and J. L. Richardson. 1994. Biogeochemical processes in hydric soils. *Current Topics in Wetland Biogeochemistry* 1:68-127.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. *BioScience* 52: 883-890.

Messina, M. G., and W. H. Conner. 1997. *Southern forested wetlands: Ecology and management.* Boca Raton, FL: Lewis Publishers.

Mitchell, J. C., I. N., M. A. Bailey, J. N. Holmes, and K. A. Buhlmann. 2004. Habitat management guidelines for amphibians and reptiles of the southeastern United States. Partners in Amphibian and Reptile Conservation Technical Publication HMG-2.

Mitsch, W. J., and J. G. Gosselink. 2000. *Wetlands. 3rd ed.* New York: John Wiley and Sons.

Miwa, M., D. L. Gartner, C. S. Bunton, R. Humphreys, C. C. Trettin. 2002. *Characterization of headwater stream hydrology in the southeastern Coastal Plain.* USDA Forest Service, Southern Research Station, The Center for Forested Wetlands Research, Final Report (IAG#: DW12945840-01-0).

Monk, C. D. 1966. An ecological study of hardwood swamps in north-central Florida. *Ecology* 47: 649-654.

_____. 1968. Successional and environmental relationships of the forest vegetation of north central Florida. *American Midland Naturalist* 79: 441–457.

Morrison, M. L. 1986. Bird populations as indicators of environmental change. *Current Ornithology* 3: 429-451.

Morrison, M. L., B. C. Marcot, and R. W. Mannan. 1992. *Wildlife Habitat Relationships: Concepts and Applications.* Madison, WI: University of Wisconsin Press.

Mount, R. H. 1975. *The reptiles and amphibians of Alabama.* Auburn, AL: Auburn University Agricultural Experiment Station.

NatureServe. 2002. *International Classification of Ecological Communities: Terrestrial Vegetation.* Natural Heritage Central Databases. Arlington, VA: NatureServe.

Nelson, J. B. 1986. *The Natural Communities of South Carolina: Initial Classification and Description.* Columbia, SC: S.C. Wildlife and Marine Resources Dept. Division of Wildlife and Freshwater Fisheries.

Nilon, C. H. 1986. Quantifying small mammal habitats along a gradient of urbanization. Ph.D. diss., State University of New York, Syracuse.

Nilon, C. H., and L. W. VanDruff. 1987. Analysis of small mammal community data and applications to management of urban greenspaces. In *Integrating man and nature in the metropolitan environment*, ed. L. W. Adams and D. L. Leedy, 53-59. Columbia, MD: National Institute for Urban Wildlife.

Noble, C. V., J. S. Wakeley, T. H. Roberts, and C. Henderson. 2007. *Regional Guidebook for applying the Hydrogeomorphic Approach to assessing the functions of Headwater Slope Wetlands on the Mississippi and Alabama Coastal Plains.* ERDC/EL TR-07-9. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

O'Connell, T. J., L. E. Jackson, and R. P. Brooks. 2000. Bird guilds as indicators of ecological condition in the central Appalachians. *Ecological Applications* 10: 1706-1721.

Ostry, R. C. 1982. Relationship of water quality and pollutant loads to land uses in adjoining watersheds. *Water Resources Bulletin* 18 (1): 99-104.

Perry, D. A. 1994. *Forest ecosystems.* Baltimore, MD: Johns Hopkins University Press.

Pugh, G., and C. H. Dickinson. 1974. *Biology of plant litter decomposition, Vol. II.* London, England: Academic Press.

Ralph, C. J., G. R. Geupel, P. Pyle, T.E. Martin, and D. F. DeSante. 1993. *Handbook of field methods for monitoring landbirds.* General Technical Report PSW-GTR-144. Albany, CA: U.S. Dept. of Agriculture, Forest Service, Pacific Southwest Research Station.

Reed, P. B. 1988. *National list of plant species that occur in wetlands: Southeast Region 2.* Biological report 88(26.2). Washington, DC: U.S. Fish and Wildlife Service.

Reiners, W. A. 1972. Terrestrial detritus and the carbon cycle. In *Carbon and the biosphere,* Conference proceedings, United States Atomic Energy Commission, ed. G. M. Woodwell and E. V. Pecan.

Rheinhardt, R. D., M. M. Brinson, and P.M. Farley. 1997. A preliminary reference data set for wet forested flats in North Carolina and its application to wetland functional assessment, mitigation, and restoration. *Wetlands* 17: 195-215.

Rhode, W. A., L. E. Asmussen, E. W. Hauser, R. D. Wauchope, and H. D. Allison. 1980. Trifluralin movement in runoff from a small agricultural watershed. *Journal of Environmental Quality* 9: 37-42.

Robbins, C. S., D. K. Dawson, and B. A. Dowell. 1989. Habitat area requirements of breeding forest birds in the middle Atlantic states. *Wildlife Monographs* 103: 1-34.

Roberts, T. H., and M. S. Peterson. 2001. *Wetland fauna and drainage basin studies: Spatial aspects of habitat use by birds in and around forested depressional and flats wetlands.* Arnold Engineering Development Center, Contract No. F40650-95-D-006, CDRL No. A005.

Robertson, P. A. 1992. Environmental factors affecting tree growth on three wetland sites in southern Illinois. *American Midland Naturalist* 128: 218-326.

Robertson, P. A., G. T. Weaver, and J. A. Cavanaugh. 1978. Vegetation and tree species patterns near the northern terminus of the southern floodplain forest. *Ecological Monographs* 48: 249-67.

Rothermel, B. B., and R. D. Semlitsch. 2002. An experimental investigation of landscape resistance of forest versus old-field habitats to emigrating juvenile amphibians. *Conservation Biology* 16: 1324-1332.

Schlesinger, W. H. 1977. Carbon balance in terrestrial detritus. *Annual review of ecology and systematics* 8: 51-81.

Schneider, D. C. 1994. *Quantitative ecology: Spatial and temporal scaling.* New York: Academic Press.

Schoener, T. W. 1986. Resource partitioning. In *Community ecology: Patterns and processes,* ed. J. Kikkawa and D. J. Anderson, 91-126. Melbourne: Blackwell.

Schroeder, R. L. 1985. *Eastern wild turkey.* Biological Report 82(10.106). Washington, DC: U. S. Fish and Wildlife Service.

Semeniuk, C. A. 1987. Wetlands of the Darling System: A geomorphic approach to habitat classification. *Journal of the Royal Society of Western Australia* 69: 95-112.

Semlitsch, R. D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. *Conservation Biology* 12: 1113-1119.

Semlitsch, R. D., and J. R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology* 17: 1219-1227.

Semlitsch, R. D., and J. B. Jensen. 2001. Core habitat, not buffer zone. *National Wetlands Newsletter* 23: 5-6.

Shafer, D. J., and D. J. Yozzo. 1998. *National guidebook for application of hydrogeomorphic assessment to tidal fringe wetlands.* Technical Report WRP-DE-16. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Shahan, A. N. 1982. Estimation of pre- and post-development nonpoint water quality loadings. *Water Resources Bulletin* 18: 231-237.

Sheffield, R. M., and M. T. Thompson. 1992. *Hurricane Hugo effects on South Carolina's forest resource.* Res. Pap. SE-284. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

Sidlow, S. F., D. J. Smith, W. Tyler, and J. C. Purvis. 1995. *General characteristics of South Carolina's climate 1961-1990 Update Volume I.* Report G-5. Columbia, SC: Water Resources Division, State Climatology Office, South Carolina Department of Natural Resources.

Singh, J. S., and S. R. Gupta. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *Botanical Review* 43: 449-528.

Smith, R. D. 2001. *Hydrogeomorphic approach to assessing wetland functions: Guidelines for developing regional guidebooks; Chapter 3, Developing a reference wetland system.* ERDC/EL TR-01-29. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Smith, R. D. and C. V. Klimas. 2002. *A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Selected Regional Wetland Subclasses, Yazoo Basin, Lower Mississippi River Alluvial Valley.* http://www.wes.army.mil/el/wetlands/pdfs/trel02-4.pdf. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Smith, R. D., and J. S. Wakeley. 2001. *Hydrogeomorphic approach to assessing wetland functions: Guidelines for developing regional guidebooks; Chapter 4, Developing assessment models.* ERDC/EL TR-01-30. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Smith, R. D., A. Amman, C. Bartoldus, and M. M. Brinson. 1995. An approach for assessing wetland functions based on hydrogeomorphic classification, reference wetlands, and functional indices. Technical Report WRP-DE-9. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Snyder, N. J, S. Mostaghimi, D. F. Berry, R. B. Reneau, and E. P. Smith. 1995. Evaluation of a riparian wetland as a naturally occurring decontamination zone. *Clean water, clean environment – 21st century. Volume III: Practices, systems, and adoption.* Proceedings of a conference March 5-8, 1995, Kansas City, MO., American Society of Agricultural Engineers, St. Joseph, Michigan, 259-262.

South Carolina Department of Health and Environmental Control (SCDHEC). 2003. *A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of headwater riverine wetlands in the Atlantic Coast Flatwoods of South Carolina.* Draft report to EPA Region 4, Atlanta.

South Carolina Department of Natural Resources State Climatology Office. 2009. http://www.dnr.sc.gov/climate/sco/ClimateData/cli_sc_climate.php

South Carolina Water Resources Commission. 1983. *South Carolina State Water Assessment.* Report No. 140. H. Stephen Synder, Project Manager.

South Carolina Water Resources Commission. 1993. *Assessing Change in the Edisto River Basin: An Ecological Characterization.* Report No. 177, ed. W. D. Marshall.

Spight, T. M. 1968. The water economy of salamanders: evaporative water loss. *Physiological Zoology* 41: 195-203.

Spurr, S. H., and B. V. Barnes. 1980. *Forest ecology.* New York: John Wiley and Sons.

Stewart, R. E., and H. A. Kantrud. 1971. *Classification of natural ponds and lakes in the glaciated prairie region.* Resource Publication 92. Washington, DC: U.S. Fish and Wildlife Service.

Strahler, A. H. 1952. Dynamic basis of geomorphology. Bulletin of the Geological Society of America, 63:923-938.

Strecker, E. W., J. M. Kernar, E. D. Driscoll, R. R. Horner, and T. E. Davenport. 1992. *The use of wetlands for controlling stormwater pollution*. Alexandria, VA: The Terrene Institute.

Strelke, W. K., and J. G. Dickson. 1980. Effect of forest clear-cut edge on breeding birds in east Texas. *Journal of Wildlife Management* 44(3): 559-567.

ter Braak, C. J. F. 1994. Canonical community ordination. Part 1: Basic theory and linear methods. *Ecoscience* 1: 127-140.

Terry, R. D., and G. V. Chilingar. 1955. Comparison charts for visual estimation of foliage cover. *Journal of Sedimentary Petrology* 25(3):229-234. Society of Economic Paleontologists.

Tritton, L. M., and J. W. Hornbeck. 1982. *Biomass equations for major tree species, the northeast*. General Technical Report NE-69. U.S. Forest Service, Northeast Forest Experiment Station.

Uranowski, C., Z. Lin, M. DelCharco, C. Huegel, J. Garcia, I. Bartsch, M. S. Flannery, S. J. Miller, J. Bacheler, and W. Ainslie. 2003. *A Regional Guidebook for applying the hydrogeomorphic approach to assessing wetland functions of low-gradient, blackwater riverine wetlands in peninsular Florida*. ERDC/EL TR-03-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

U.S. Army Corps of Engineers. 1988. *A guide to selected Florida wetland plants and communities*. Jacksonville District Publication CESAJP 1145-2-1.

U.S. Department of Agriculture. 1981. *Land resource regions and Major Land Resource Areas of the United States*. U.S. Department of Agriculture Soil Conservation Handbook 296.

U.S. Department of Agriculture (USDA) Natural Resources Conservation Service. 1986. *Urban hydrology for small watersheds*. Technical Release 55 (TR-55). Washington, DC.

U.S. Department of Agriculture (USDA) Natural Resources Conservation Service. 2006. *Land Resources Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin, Agriculture Handbook 296*. Washington, DC: U.S. Department of Agriculture.

U.S. Forest Service. 1980. Wildlife habitat management handbook, southern region, FSH-2609.23R. Washington, DC: U.S. Forest Service.

VanDruff, L. W., E. G. Bolen, and G. J. San Julian. 1996. Management of urban wildlife. In *Research and management techniques for wildlife and habitats,* Fith ed., ed. Bookhout, T. A. 507-530. Bethesda, MD: The Wildlife Society.

VanDruff, L. W., and R. N. Rowse. 1986. Habitat association of mammals in Syracuse, New York. *Urban Ecology* 9: 413-434.

Vince, S. W., S. R. Humphrey, and R. W. Simons. 1989. *The ecology of hydric hammocks: A community profile*. Biological Report 85(7.26). U.S. Fish and Wildlife Service.

Vogt, K. A., C. C. Grier, and D. J. Vogt. 1986. Production, turnover, and nutrient dynamics of above and belowground detritus of world forests. *Advances in Ecological Research* 15: 303-77.

Wakeley, J. S., and T. H. Roberts. 1996. Bird distribution and forest zonation in a bottomland hardwood wetland. *Wetlands* 16: 296-308.

Wakeley, J. S. and R. D. Smith. 2001. *Hydrogeomorphic Approach to Assessing Wetland Functions: Guidelines for Developing Regional Guidebooks - Chapter 7 Verifying, Field Testing, and Validating Assessment Models*. ERDC/EL TR-01-31. Vicksburg, MS: U.S. Army Engineer Research and Development Center. (http://el.erdc.usace.army.mil/wetlands/pdfs/trel01-31.pdf).

Wharton, C. H., H. T. Odum, K. Ewel, M. Duever, A. Lugo, R. Boyt, J. Bartholomew, E. DeBellevue, S. Brown, M. Brown, and L. Duever. 1977. *Forested wetlands of Florida – their management and use*. Gainsville, FL: Center for Wetlands, University of Florida.

Wharton, C. H., W. M. Kitchens, E. C. Pendleton, and T. W. Sipe. 1982. *The ecology of bottomland hardwood swamps of the southeast: A community profile*. Report FWS/OBS-81/37. Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services.

Whitlock, A. L., N. M. Jarman, and J. S. Larson. 1994. *WEThings; Wetland Habitat Indicators for Nongame Species, Wetland-Dependent Amphibians, Reptiles and Mammals of New England*. Publication 94-1. Amherst, MA: The Environmental Institute, University of Massachusetts.

Whittaker, R. H. 1975 *Communities and ecosystems.* New York: MacMillan Publishing Company.

Whittaker, R. H., F. H. Bormann, G. E. Likens, and T. G. Siccama. 1974. The Hubbard Brook Ecosystem Study: Forest biomass and production. *Ecological Monographs* 44: 233-54.

Wiens, J. A. 1969. An approach to the study of ecological relationships among grassland birds. *Ornithological Monographs* 8: 1-93.

Wilcove, D. 1985. Nest predation in forest tracts and the decline of migratory songbirds. *Ecology* 66: 1211-14.

Williams, T.M. 1998. Hydrology. In *Southern Forested Wetlands: Ecology and Management,* ed. M.G. Messina and W.H. Conner. Boca Raton, FL: Lewis Publishers.

Willson, M. F. 1974. Avian community organization and habitat structure. *Ecology* 55: 1017-1029.

Young, R. A., T. Huntrods, and W. Anderson. 1980. Effectiveness of riparian buffer strips in controlling pollution from feedlot runoff. *Journal of Environmental Quality* 9: 483-487.

Zarbock, H., A. Janicki, D. Wade, D. Heimbuch, and H. Wilson. 1994. *Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida.* St. Petersburg, FL: Tampa Bay National Estuary Program.

Zedler, P. H. 1987. *The ecology of southern California vernal pools: A community profile.* Biological Report 85(7.11). Washington, DC: U.S. Fish and Wildlife Service.

Appendix A: Glossary

Assessment Model: A model that defines the relationship between ecosystem and landscape scale variables and functional capacity of a wetland. The model is developed and calibrated using reference wetlands from a reference domain.

Assessment Objective: The reason an assessment of wetland functions is conducted. Assessment objectives normally fall into one of three categories: documenting existing conditions, comparing different wetlands at the same point in time (e.g. alternatives analysis), and comparing the same wetland at different points in time (e.g. impacts analysis or mitigation success).

Assessment Team (A-Team): An interdisciplinary group of regional and local scientists responsible for classification of wetlands within a region, identification of reference wetlands, construction of assessment models, definition of reference standards, and calibration of assessment models.

Canopy tree: Self-supporting woody plants ≥10 cm (4 in.) dbh, whose crowns comprise the uppermost stratum of the vegetation. Canopy trees are not immediately overtopped by taller trees and would be clearly seen by an airborne observer (Figure 11)**.**

Catchment: The geographic area where surface water would flow or run off into the headwater wetland.

Curve number: A dimensionless parameter that varies from 0 to 100 and provides an indication of runoff potential.

Detritus: The soil layer dominated by partially decomposed but still recognizable organic material, such as leaves, sticks, needles, flowers, fruits, insect frass, dead moss, or detached lichens on the surface of the ground. This material would classify as fibric or hemic material (peat or mucky peat).

Diameter at Breast Height (DBH): Tree diameter measured at 1.4 m (55 in.) above the ground.

Direct impacts: Project impacts that result from direct physical alteration of a wetland, such as the placement of dredge or fill.

Direct measure: A quantitative measure of an assessment model variable.

Exotics: See **Invasive species**.

Facultative species (FAC): A plant species equally likely to occur in wetlands or non-wetlands (estimated probability of occurrence in wetlands 34-66 percent).

Facultative upland species (FACU): A plant species that usually occurs in non-wetlands but sometimes is found in wetlands (estimated probability of occurrence in wetlands 1-33 percent).

Facultative wetland species (FACW): A plant species that usually occurs in wetlands (estimated probability 67-99 percent), but sometimes is found in non-wetlands.

Functional assessment: The process by which the capacity of a wetland to perform a function is measured. This approach measures capacity using an assessment model to determine a functional capacity index.

Functional capacity: The rate or magnitude at which a wetland ecosystem performs a function. Functional capacity is dictated by characteristics of the wetland ecosystem and the surrounding landscape, and interaction between the two.

Functional Capacity Index (FCI): An index of the capacity of a wetland to perform a function relative to other wetlands in a regional wetland subclass. Functional Capacity Indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates the wetland is performing a function at the highest sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in a reference domain. An index of 0.0 indicates the wetland does not perform the function at a

measurable level, and will not recover the capacity to perform the function through natural processes.

Ground layer: The layer of vegetation consisting of all herbaceous plants, regardless of height, and woody plants less than 1 m (39 in.) tall.

Highest sustainable functional capacity: The level of functional capacity achieved across the suite of functions performed by a wetland under reference standard conditions in a reference domain. This approach assumes the highest sustainable functional capacity is achieved when a wetland ecosystem and the surrounding area are undisturbed.

Hydrogeomorphic unit: Hydrogeomorphic units are areas within a wetland assessment area that are relatively homogeneous with respect to ecosystem scale characteristics such as microtopography, soil type, vegetative communities, or other factors that influence function. Hydrogeomorphic units may be the result of natural or anthropogenic processes.

Hydrogeomorphic wetland class: The highest level in the hydrogeomorphic wetland classification. There are five basic hydrogeomorphic wetland classes: depression, riverine, slope, fringe, and flat.

Hydrologic Soil Group: Soils are classified by the Natural Resources Conservation Service into four groups based on the soil's runoff potential. The four groups are A, B, C, and D. Soils in group A have the least runoff potential and soils in group D have the highest runoff potential.

Hydroperiod: The annual duration of flooding (in days per year) at a specific point in a wetland.

Indicator: Observable characteristics that correspond to identifiable variable conditions in a wetland or the surrounding landscape.

Indirect impacts: Impacts resulting from a project that occur concurrently, or at some time in the future, away from the point of direct impact. For example, indirect impacts of a project on wildlife can result from an increase in the level of activity in adjacent, newly developed areas, even though the wetland is not physically altered by direct impacts.

Indirect measure: A qualitative measure of an assessment model variable that corresponds to an identifiable variable condition.

Invasive species: Generally, exotic species without natural controls that out-compete native species.

Jurisdictional wetland: Areas that meet the soil, vegetation, and hydrologic criteria described in the "Corps of Engineers Wetlands Delineation Manual" (Environmental Laboratory 1987) or its successor. Not all wetlands are regulated under Section 404.

Mitigation plan: A plan for replacing lost functional capacity resulting from project impacts.

Mitigation wetland: A restored or created wetland that serves to replace functional capacity lost as a result of project impacts.

Mitigation: Restoration or creation of a wetland to replace functional capacity that is lost as a result of project impacts.

Model variable: A characteristic of the wetland ecosystem or surrounding landscape that influences the capacity of a wetland ecosystem to perform a function.

Obligate upland (UPL): A plant species that almost always occurs in non-wetlands under natural conditions (estimated probability of occurrence in wetlands <1 percent).

Obligate wetland (OBL): A plant species that almost always occurs in wetlands (estimated probability >99 percent) under natural conditions.

Organic matter: Plant and animal residue in the soil in various stages of decomposition.

Organic soil material: Soil material that is saturated with water for long periods or artificially drained and, excluding live roots, has an organic carbon content of 18 percent or more with 60 percent or more clay, or 12 percent or more organic carbon with 0 percent clay. Soils with an intermediate amount of clay have an intermediate amount of organic

carbon. If the soil is never saturated for more than a few days, it contains 20 percent or more organic carbon.

Oxidation: The loss of one or more electrons by an ion or molecule.

Partial Wetland Assessment Area (PWAA): A portion of a WAA that is identified a priori, or while applying the assessment procedure to an area relatively homogeneous and different from the rest of the WAA with respect to one or more variables. Differences may be natural or result from anthropogenic disturbance.

Project alternative(s): Different ways in which a given project can be done. Alternatives may vary in terms of project location, design, method of construction, amount of fill required, and other ways.

Project area: The area that encompasses all activities related to an ongoing or proposed project.

Project target: The level of functioning identified for a restoration or creation project. Conditions specified for the functioning are used to judge whether a project reaches the target and is developing toward site capacity.

Red flag features: Features of a wetland or surrounding landscape to which special recognition or protection is assigned on the basis of objective criteria. The recognition or protection may occur at a Federal, State, regional, or local level and may be official or unofficial.

Reference domain: All wetlands within a defined geographic area that belong to a single regional wetland subclass.

Reference standards: Conditions exhibited by a group of reference wetlands that correspond to the highest level of functioning (highest sustainable capacity) across the suite of functions of the regional wetland subclass. By definition, highest levels of functioning are assigned an index of 1.0.

Reference wetlands: Wetland sites that encompass the variability of a regional wetland subclass in a reference domain. Reference wetlands are

used to establish the range of conditions for construction and calibration of functional indices and to establish reference standards.

Region: A geographic area that is relatively homogeneous with respect to large-scale factors such as climate and geology that may influence how wetlands function.

Regional wetland subclass: Regional hydrogeomorphic wetland classes that can be identified based on landscape and ecosystem scale factors. There may be more than one regional wetland subclass for each of the hydrogeomorphic wetland classes that occur in a region, or there may be only one.

Runoff: Water flowing on the surface either by overland sheet flow or by channel flow in rills, gullies, streams, or rivers.

Sapling/shrub layer: For the purposes of this guidebook, the vegetation layer consisting of self-supporting woody plants greater than 1 m (39 in.) in height but less than 10 cm (4 in.) in diameter at breast height.

Seasonal high water table: The shallowest depth to free water that stands in an unlined borehole or where the soil moisture tension is zero for a significant period (for more than a few weeks).

Site potential: The highest level of functioning possible, given local constraints of disturbance history, land use, or other factors. Site capacity may be equal to or less than levels of functioning established by reference standards for the reference domain, and it may be equal to or less than the functional capacity of a wetland ecosystem.

Soil surface: The soil surface is the top of the mineral soil; or, for soils with an O horizon, the soil surface is the top of the part of the O horizon that is at least slightly decomposed. Fresh leaf or needle fall that has not undergone observable decomposition is excluded from soil and may be described separately (Carlisle 2000).

Value of wetland function: The relative importance of wetland function or functions to an individual or group.

Variable: An attribute or characteristic of a wetland ecosystem or the surrounding landscape that influences the capacity of the wetland to perform a function.

Variable condition: The condition of a variable as determined through quantitative or qualitative measure.

Variable index: A measure of how an assessment model variable in a wetland compares to the reference standards of a regional wetland subclass in a reference domain.

Watershed: The geographic area that contributes surface runoff to a common point, known as the watershed outlet.

Wetland: In Section 404 of the Clean Water Act "areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal conditions do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." The presence of water at or near the surface creates conditions leading to the development of redoximorphic soil conditions, and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

Wetland assessment area (WAA): The wetland area to which results of an assessment are applied.

Wetland ecosystems: In 404: "....... areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (Corps Regulation 33 CFR 328.3 and EPA Regulations 40 CFR 230.3). In a more general sense, wetland ecosystems are three-dimensional segments of the natural world where the presence of water at or near the surface creates conditions leading to the development of redoximorphic soil conditions, and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

Wetland functions: The normal activities or actions that occur in wetland ecosystems, or simply, the things that wetlands do. Wetland functions result directly from the characteristics of a wetland ecosystem and the surrounding landscape, and their interaction.

Wetland restoration: The process of restoring wetland function in a degraded wetland. Restoration is typically done as mitigation.

Appendix B: Supplementary Information on Model Variables

This appendix contains the following information:

a. Comparison Charts for Visual Estimation of Foliage Cover

b. Hydrologic Groups for Soils

c. Weighted Average Method for Determining V_{UPUSE}

d. Determining the Subindex Score for V_{SSOM}

e. Hand Calculating Worksheet for Calculation Woody Debris Volume

Comparison Charts for Visual Estimation of Foliage Cover[1]
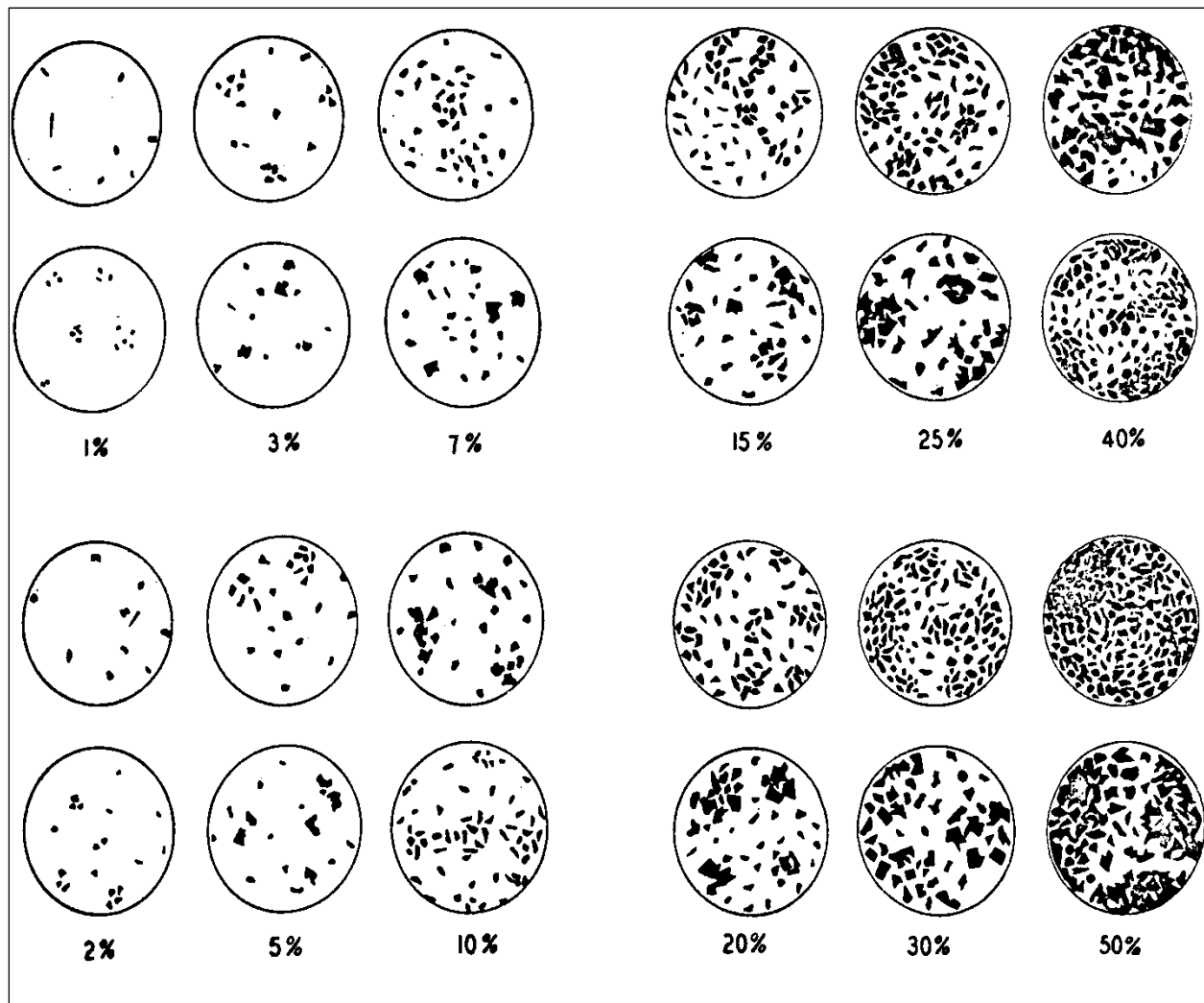
Table B1. Hydrologic Soil Groups for Soils in the Reference Domain.

Soil Component	Hydrologic Group[1]	Soil Component	Hydrologic Group	Soil Component	Hydrologic Group	Soil Component	Hydrologic Group
Ailey	B	Candor	A	Dunbar	D	Handsboro	D
Alaga	A	Cantey	D	Duplin	C	Haplaquents	D
Alamance	B	Cape Fear	D	Durham	B	Helena	C
Albany	C	Capers	D	Echaw	A	Herndon	B
Alpin	A	Caroline	C	Eddings	B	Hiwassee	B
Altavista	C	Cartecay	C	Edisto	C	Hobcaw	D
Appling	B	Cecil	B	Elloree	D	Hobonny	D
Argent	D	Centenary	A	Emporia	C	Hornsville	C
Autryville	A	Charleston	C	Enon	C	Hyde	B/D
Badin	B	Chastain	D	Enoree	D	Iredell	C/D
Barnwell	C	Chenneby	C	Eulonia	C	Izagora	B
Bayboro	D	Chewacla	C	Eunola	C	Jedburg	C
Beaches	D	Chipley	C	Faceville	B	Johns	C
Bethera	D	Chisolm	A	Fluvaquents	D	Johnston	D
Bibb	D	Clarendon	C	Foreston	C	Kalmia	B
Bladen	D	Clay Pit	B	Foxworth	A	Kenansville	A
Blaney	B	Claycreek	C	Fripp	A	Kershaw	A
Blanton	A	Clayham	B	Fuquay	B	Kiawah	B/D
Bohicket	D	Congaree	B	Georgeville	B	Kinston	B/D
Bonneau	A	Coosaw	B	Goldsboro	B	Kirksey	C
Borrow Pit	A	Cowarts	C	Goldston	C	Lakeland	A
Brogdon	B	Coxville	D	Gourdin	C	Lenoir	D
Brookman	D	Craven	C	Grady	D	Leon	B/D
Buncombe	A	Daleville	D	Gravel Pit	A	Levy	D
Butters	B	Dasher	D	Greenville	B	Lignum	C
Byars	D	Dorovan	D	Grifton	D	Lucknow	A
Cahaba	B	Dothan	B	Gundy	C	Lucy	A
Lugoff	B	Ocilla	C	Quartzipsam-ments	A	Torhunta	C
Lumbee	B/D	Ogeechee	B/D	Rains	B/D	Totness	D

[1] Adapted from USDA Soils Surveys from reference domain. If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas.

Soil Component	Hydrologic Group[1]	Soil Component	Hydrologic Group	Soil Component	Hydrologic Group	Soil Component	Hydrologic Group
Lynchburg	C	Okeetee	D	Red Bay	B	Troup	A
Lynn Haven	B/D	Olanta	B	Rembert	D	Uchee	A
Madison	B	Orange	D	Ridgeland	B/D	Udifluvents	D
Marlboro	B	Orangeburg	B	Rimini	A	Udipsammen ts	A
Marvyn	B	Osier	A/D	Rion	B	Udorthents	B
Mayodan	B	Pacolet	B	Riverview	B	Udorthents, refuse substratum	C
Mccoll	D	Pactolus	A	Rutlege	B/D		
Mecklenburg	C	Pageland	C	Santee	D	Varina	C
Meggett	D	Paleaquults	B/D	Scranton	A/D	Vaucluse	C
Mouzon	D	Pamlico	D	Seagate	A/D	Wadmalaw	D
Mullers	D	Pantego	B/D	Seewee	B	Wagram	A
Murad	B	Paxville	B/D	Smithboro	D	Wahee	D
Myatt	D	Pelham	B/D	Stallings	C	Wateree	B
Nahunta	C	Pelion	B/D	State	B	Wedowee	B
Nankin	C	Persanti	C	Suffolk	B	Wehadkee	D
Nansemond	C	Pickens	C/D	Summerton	B	Wickham	B
Nason	C	Pickney	A/D	Tarboro	A	Williman	B/D
Neeses	C	Plummer	B/D	Tatum	B	Winnsboro	D
Nemours	C	Pocalla	A	Tawcaw	C	Witherbee	A/D
Newhan	A	Pocomoke	B/D	Tetotum	C	Woodington	B/D
Noboco	B	Poindexter	B	Thursa	B	Yauhannah	B
Norfolk	B	Ponzer	D	Toccoa	B	Yemassee	C
Ochlockonee	B	Pungo	D	Tomahawk	A	Yonges	D

Weighted Average Method for Determining V_{UPUSE}

The following example shows how to estimate the weighted average runoff score for V_{UPUSE}:

Identify the different land-use types within the catchment of the WAA using recent aerial photography (Figure B1). Estimate the percentage of the catchment in each land-use type. Verify during onsite reconnaissance.

Figure B1. Aerial photograph illustrating the cover types found within the catchment of a wetland.

Identify the soils within the catchment and determine the hydrologic soil group (A, B, C, or D) based on the soil series identified for the area in the appropriate soil survey. In this example, all of the soils are in hydrologic soil group D.

Table B2. V_{UPUSE} Example

Cover Type	Percent of Catchment	Runoff Curve Numbers
Forest and native range (>75% ground cover)	75	77
Residential (65% cover)	10	92
Open space good condition (>75% cover)	15	80
Total	100	

Determine the runoff curve number for each combination of land-use and hydrologic soil group present (Table B2).
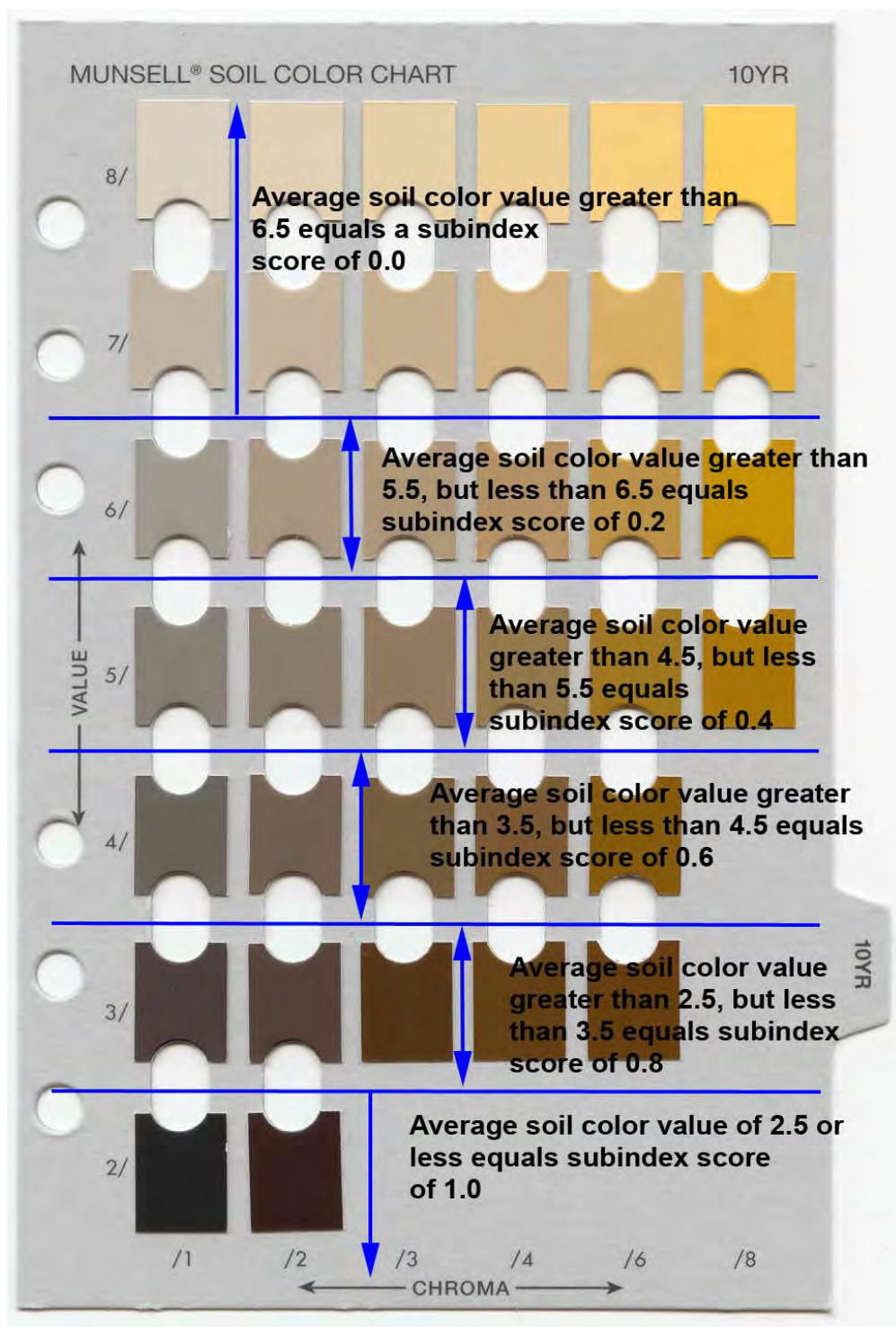
Multiply the runoff curve number by the percentage of the catchment, sum these products across the entire catchment and divide by 100.

For this example, the weighted average runoff score is:

$$\left[\frac{(77 \times 75) + (92 \times 10) + (80 \times 15)}{100} \right] = 78.95$$

Using the graph for V_{UPUSE}, determine the variable subindex score that corresponds to a runoff score of 78.95 (round to 79) (Figure 6). The variable subindex score for this example is 0.44.

Determining the subindex score for surface soil organic matter (V_{SSOM}) by averaging the soil color values from all subplots. Due to inaccurate color reproduction, do not use this page to determine soil colors in the field.

MUNSELL® SOIL COLOR CHART — 10YR

Average soil color value greater than 6.5 equals a subindex score of 0.0

Average soil color value greater than 5.5, but less than 6.5 equals subindex score of 0.2

Average soil color value greater than 4.5, but less than 5.5 equals subindex score of 0.4

Average soil color value greater than 3.5, but less than 4.5 equals subindex score of 0.6

Average soil color value greater than 2.5, but less than 3.5 equals subindex score of 0.8

Average soil color value of 2.5 or less equals subindex score of 1.0

Hand Calculations for Determining V_{WD}

If you do not wish to use the spreadsheet calculator to calculate woody debris volume and V_{WD}, you can calculate the same summary data manually. Transfer the transect data recorded on the plot data sheets to the worksheet below, and make the indicated calculations.

From the plot data sheet, transfer the small woody debris stem counts (Size Class 1 - stems between 0.6 and 2.54 cm in diameter) for Transects 1 and 2, sum them, and multiply by 0.722 to convert to volume per hectare:
Stem Count, Transect 1 ____
Stem Count, Transect 2 ____
total number of stems = _____ × 0.722 = _____ m³/ha, Size Class 1

From the plot data sheet, transfer the medium woody debris stem counts (Size Class 2 - stems between 2.54 and 7.6 cm in diameter) for Transects 1 and 2, sum them, and multiply by 3.449 to convert to volume per hectare:
Stem Count, Transect 1 ____
Stem Count, Transect 2 ____
total number of stems = _____ × 3.449 = _____ m³/ha, Size Class 2

From the plot data sheet, transfer the diameter (cm) of each stem of Size Class 3 (large stems, > 7.6 cm, or >3 inches) measured along Transect 1 and Transect 2 into the table below. Multiply each diameter measurement by 0.3937, and then square the result. Sum all results, then multiply that sum by 0.2657 to get large woody debris volume (m³/ha).

Transect 1			Transect 2		
1	2	3	1	2	3
Stem Diameter (cm)	Multiply stem diameter by 0.3937	Square the result in column 2	Stem Diameter (cm)	Multiply stem diameter by 0.3937	Square the result in column 2
SUM=			SUM=		
Sum of Size Class 3 Transect 1 + Sum of Size Class 3 Transect 2 = _____ × 0.2657 = _____ m³/ha, Size Class 3					
Sum of Size Class 1 _____m³/ha + Size Class 2 _____m³/ha + Size Class 3 _____m²/ha = _____ m³/ha (total woody debris volume/ha)					

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14. ABSTRACT

The Hydrogeomorphic (HGM) Approach is a system for developing functional indices to assess a wetland's capacity to perform functions similar to those of comparable wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence. This Regional Guidebook (a) characterizes the Headwater Slope wetlands on the South Carolina Coastal Plain, (b) describes and provides the rationale used to select functions for the Headwater Slope wetland subclass, (c) describes model variables and metrics, (d) describes the development of assessment models, (e) provides data from reference wetlands and documents their use in calibrating model variables and assessment models, and (f) outlines protocols for applying the functional indices to the assessment of wetland functions.

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